ISBN 0-7729-2804-5

ENVIRONMENTAL NOISE ASSESSMENT IN LAND USE PLANNING

1987

Ontario

Ministry
of the
Environment

The Honourable
Jim Bradley
Minister

Rod McLeod
Deputy Minister

ERRATA SHEET

Note 1: Add the following to page 14-5 after section 1.2

1.3 Mechanical Ventilation

When the adjusted noise level at the building facade exceeds 60 dBA, it is the policy of this Ministry to recommend central airconditioning to ensure that the windows may remain closed. In high density condominium or rental residential developments, central airconditioning may not be practical or economically feasible and other forms of mechanical ventilation may be preferable.

The Ministry accepts this option with the following conditions:

a) the Municipality approves its use, and

b) the ventilation system complies with all applicable national, provincial or municipal standards and codes, and

c) the ventilation system allows the windows to remain closed.

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THIS PUBLICATION HAS BEEN PREPARED
BY THE ONTARIO MINISTRY OF THE ENVIRONMENT
TO COMPLIMENT EXISTING ENVIRONMENTAL LEGISLATION

THIS DOCUMENT IS BASED ON THE
PROVISIONS OF THE PLANNING ACT AND
THE ENVIRONMENTAL PROTECTION ACT

FIRST REVISION
FEBRUARY 1987

Copies may be purchased, by writing to:

Publications Centre
880 Bay Street
5th Floor
Toronto, Ontario
M7A 1N8

OR

Ontario Government Bookstore
880 Bay Street
Toronto, Ontario
M7A 1N8

The Noise Assessment and System Support Unit,
Environmental Approvals and Land Use Planning Branch,
Ontario Ministry of the Environment,
is entirely responsible for the scope, format
and development of the course contained herein.

Head, Noise Assessment and System Support Unit:	L.G. Kende, MASc., P. Eng.
Editor-in-Chief and Project Co-ordinator:	R. Ramakrishnan, PhD., P. Eng.
Contributors:	S. Benner, M.ASc., P. Eng. C. Chiu, P. Eng. L. Feldman, M.E.S. C. Krajewski, MSc., P. Eng. R. Krawczyniuk, MSc. V. Schroter, PhD.

ABSTRACT

The present publication is a revision of a manual published in 1978 by the Ministry titled "Acoustics Technology in Land Use Planning".

While this publication is in a textbook format, serving as a reference manual for the certificate course "Environmental Noise Assessment in Land Use Planning", it also summarizes the principles and procedures used for noise assessment forming a seed document for the preparation of policies.

The document covers the following topics: Land use planning concepts and procedures, Planning process in Ontario, Fundamentals of sound and vibration, Analysis of community noise, Sound level limits and criteria, Prediction of road and rail traffic noise levels, Aircraft noise contours, Analysis of noise control measures, Prediction of sound barrier attenuation, Building acoustics and materials, Measurement of sound levels, Calculation workshop, Implementation procedures and report writing, and Ministry review procedures.

RÉSUMÉ

La présente publication est la révision du manuel intitulé Accoustical Technology in Land Use Planning (Technologie acoustique dans la planification de l'utilisation du sol), publié par le Ministère en 1978.

Le manuel sert de référence aux étudiants du cours intitulé Environmental Noise Assessment in Land Use Planning (Évaluation de l'environnement acoustique dans la planification de l'utilisation du sol) menant à l'obtention d'un certificat. Comme en outre il résume les principes et méthodes de l'évaluation du bruit, il constitue le document de référence pour l'élaboration des règles.

Le texte porte sur les sujets suivants : planification de l'utilisation du sol (concepts et méthodes); processus de la planification en Ontario; principes de base de l'acoustique et de la vibration; analyse du bruit dans les localités; seuils et critères des niveaux sonores; prévision des niveaux sonores de la circulation routière et ferroviaire; courbes du niveau sonore des aéronefs; analyse des mesures de lutte contre le bruit; prévision de la réduction du bruit par les barrières acoustiques; acoustique des bâtiments et matériaux de construction ; mesure des niveaux sonores; ateliers sur le calcul des niveaux sonores; méthodes de mise en application et rédaction de rapports; méthodes d'examen du Ministère.

ACKNOWLEDGEMENTS

The Ontario Ministry of the Enviornment acknowledges the use of material from the following sources in the preparation of this course manual.

National Research Council of Canada

- Dr. J.D. Quirt
  Institute for Research in Construction

Bruel & Kjaer

Canada Mortgage & Housing Corporation

Gen Rad Company

Rion Co. Ltd.

Larson - Davis Laboratories

Quest Electronics

CEL Limited

Monarch International Inc.

Sierra Instruments Inc.

Metrosonics Inc.

St. Lawrence Housing Project, Toronto

- City of Toronto Housing Department
- Mr. Irving Grossman, Architect
- Toronto Star (Reporter Janice Dineen)

Townhouse Development, Harris Avenue,
  Brantford, Ontario

- Munro, Ploen & Associates Ltd.

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CHAPTER 1

NOISE AND VIBRATION ASSESSMENT IN THE PLANNING PROCESS

1.0 NOISE AND THE PLANNING PROCESS

The major objective of the planning process in Ontario is to minimize the potential for conflict through the effective planning and design of new land use.

Within the planning process all new development or redevelopment of lands in Ontario is strictly regulated through the provisions of the Planning Act (1983). This Act prescribes general rules for land use planning, establishes how land uses may be controlled and who may control them.

The Ministry of the Environment is concerned with all aspects of land use planning which may affect or be affected by the environment. The Ministry receives its authority to provide input into the planning process through provisions contained in the Planning Act. The Ministry provides comments and recommendations with regard to land use planning on all matters relating to its mandate - the protection, conservation and management of the natural environment. Subjects of concern to the Ministry include sound and vibration defined in the Environmental Protection Act as being environmental contaminants.

2.0 EFFECTS OF NOISE ON THE COMMUNITY

Noise pollution, a by-product of our society's demand for improved transportation and more material goods, is rapidly become a major environmental concern in Ontario.

The sounds in most urban communities originate from many different sources. Often sounds from transportation systems, local industry, commercial establishments, as well as a large number of other sources such as dogs barking and children playing can be heard. Due to the variety and fluctuating nature of the sounds heard in most urban communities, several descriptors (see Chapter 5) are often required to assess the impacts these sounds may have on the local residents.

The types of sounds which can be controlled through land use planning and thus pertinent to our discussion are those generated by industry/commerce and transportation (i.e. sounds due to road/rail traffic, and aircraft). Other types of sounds such as the sounds from lawn mowers, construction equipment and so forth can be effectively controlled through noise by-laws.

Recent studies have shown that community noise in general and industrial or transportation noise in particular has at least four major effects on people. First, it can interfere with spoken communication and the ability to enjoy television, radio or recorded material. A second major effect is its interference with relaxation and sleep. Decrease in work efficiency due to loss of attention is its third major effect. Finally, as a consequence of these three identifiable direct impacts, noise causes annoyance with the subsequent loss in the

feeling of well being and the enjoyment of one's property.

In extreme cases, noise may cause adverse health effects. Although at present information is simply too sparse to attribute certain health problems to community noise with reasonable certainty, it is known that noise causes stress and therefore contributes to a large number of physical, emotional and mental disorders.

3.0 NOISE CONTROL THROUGH LAND USE PLANNING

Only recently have most municipalities in Ontario realized the importance of the preventive measures available through land use planning in controlling the increasing noise problems within their communities.

The following provides an overview of the control of community noise through the planning process. Details on this wide ranging topic are discussed in subsequent chapters.

3.1 General Procedure

Although noise control measures may be applied at various stages in the development of a community, the general procedure remains essentially the same. After establishing the locations of the noise sources and their sound characteristics, the sound levels at sensitive locations are determined either through measurements and/or through prediction techniques. The severity of noise impacts is determined by comparing the noise level to the Ministry criteria. If impact is substantial, proper control measures are designed depending on cost, practicality and effectiveness.

3.2 Major Control Mechanisms

The major control mechanisms available at the various stages in the planning of a community include:

3.2.1 Official Plans

Opportunities for the application of effective noise control measures are available at this early stage in the planning process.

Major noise control measures which may be applied include:

(a) spatial separation between sensitive and noise producing land uses and the suitable arrangement of lands within each type of land use; and

(b) policies aimed at:

- protecting planned sound sensitive developments against impacts from existing/future generators of noise; and
- controlling noise emissions from planned industries, commercial establishments, transportation systems and other noise sources such as pits and quarries.

3.2.2 Zoning By-Laws

Noise control measures may be incorporated into a zoning by-law to deal with a site specific situation where a noise problem has been identified. If a rezoning due to a proposed development is

necessary, opportunities exist through the zoning by-law for the municipality to request the implementation of noise control measures.

3.2.3 Plans of Subdivision

In keeping with the requirements imposed by the Planning Act on the owner of the land to be subdivided, namely, "regard for the health,...and welfare of the present and future inhabitants of the local municipality", noise control measures may be applied through the conditions of approval for the proposed subdivision.

Land uses which generate noise, depending on the type of noise and source ownership: (a) will be subject to the Environmental Assessment Act; or (b) will require a Certificate of Approval according to the requirements of the Environmental Protection Act. Land uses which generate noise are not discussed in this manual.

With regard to noise sensitive developments, various noise control measures are available to achieve acceptable sound levels for the future inhabitants. These control measures are discussed in detail in Chapters 8, 9 and 10. In brief, they include:

- ° site planning techniques;
- ° acoustic barriers;
- ° architectural design;
- ° construction techniques.

The last two control measures relate specifically to indoor sound levels.

The details of other planning procedures where similar control mechanisms are feasible are given in Chapter 2.

3.3 Review Process

The Ministry of the Environment may be requested to provide recommendations on noise issues at any stage in the development of a community. These recommendations will normally be provided by regional staff or if the situation is complex by staff from the Noise Assessment Unit within the Environmental Approvals and Land Use Planning Branch.

Where a development adjacent to a pit or quarry is proposed, in addition to noise, vibration levels resulting from blasting operations will also be assessed. Other common sources of vibration impact and the status of the development of vibration criteria for these sources are discussed in Chapter 4.

The process involved in the review of proposed noise sensitive developments from the noise aspect will be discussed in Chapter 14.

CHAPTER 2

PLANNING PROCESS IN ONTARIO

1.0 THE ROLE OF THE MINISTRY OF THE ENVIRONMENT IN THE PLANNING PROCESS

The Ministry of the Environment makes comments and recommendations on land use planning matters related to its mandate, which covers sound, air quality, water quality and quantity, servicing (including water, sewage, and waste management), and significant land use conflicts.

This mandate is derived from the Environmental Protection Act (EPA), the Ontario Water Resources Act (OWRA), the Environmental Assessment Act (EAA), and the Pesticides Act. It is further clarified through MOE policies contained in the Manual of Environmental Policies and Guidelines.

The Ministry of the Environment's involvement in Land Use Plan Review is part of the Ministry's preventative approach to protecting the environment. By ensuring that environmental problems are minimized at the earliest possible stage in a development proposal, the need for expensive abatement controls later on is avoided.

Environmental land use planning has a number of advantages. First, it helps prevent pollution problems before they occur. Second, planning allows more options to be considered and the best possible solution to be chosen, before deciding on development details. Land use conflicts, therefore, can be minimized or prevented. Third, it is a cheaper and more effective means of prevention than pollution control. If abatement measures

are still required after planning, the amount and expense of the measures can be reduced. The benefits of land use planning bear directly on the Ministry of the Environment's responsibility for environment quality, and so, the municipal planning process is important to the Ministry.

2.0 THE PLANNING PROCESS IN ONTARIO

Information about the basic purpose of planning is contained in "An Introduction to Community Planning", available from the Ontario Government Bookstore. As well, a series of "Citizen's Guides" has been prepared by the Ministry of Municipal Affairs concerning land use planning in Ontario. In total, there are eight "guides" which can be obtained from the various Regional Offices of the Ministry of Municipal Affairs.

Although elimination or control of the source of pollution is usually the primary objective, there are limits to what is practically and technologically possible. Due to the practical limits of control methods, planners share the responsibility of providing an acceptable level of environmental quality.

2.1 Legislation

The Ontario Planning Act is administered by the Minister of Municipal Affairs. Under the Act, the province's role is to administer municipal planning controls and perform approval functions required of the Minister of Municipal Affairs; to co-ordinate planning activities of municipalities; to look after broad provincial interests, such as the protection of farm land and natural resources; and to give direction and advice to municipalities on land use planning issues.

The Ontario Planning Act sets out the ground rules for land use planning in Ontario, and establishes how land uses may be controlled, and who may control them. The Act provides the basis for consideration of provincial interests related to municipal land use planning, such as the management of natural resources; local planning administration, including planning boards in northern Ontario; preparation of official policies and plans to guide future development; regulation and control of land use through zoning by-laws and minor variances; division of land into lots for sale or development by plan of subdivision; and the rights of Ontario citizens to be informed about planning proposals, to voice their views before the elected municipal council, and to appeal land use planning decisions to the Ontario Municipal Board.

Section 4 of the Planning Act allows the Minister of Municipal Affairs to delegate any of his authority, except the authority to approve its own official plan and amendments, to a municipal council. Once delegation occurs, the municipality is responsible for all matters normally dealt with by the Minister, including the referral of any matter to the Ontario Municipal Board (O.M.B.). Only upper-tier municipalities are eligible to receive the authority to approve local official plans and amendments. Any municipality or planning board is eligible to receive the authority to approve plans of subdivision and condominium. Delegation would include the authority to approve part lot control by-laws.

Legislation setting out the power and responsibilities of municipalities are as follows:

1. The Municipal Act.
2. The various acts establishing the regional municipalities.
3. The Ontario Planning Act.

Other legislation having a bearing on land use planning is plentiful. Examples are:

1. The Condominium Act
2. The Environmental Protection Act
3. The Ontario Water Resources Act
4. The Environmental Assessment Act
5. Beach Protection Act
6. Pits and Quarries Control Act
7. Conservation Authorities Act
8. The Public Lands Act
9. The Land Drainage Act
10. The Expropriation Act
11. The Ontario Planning and Development Act
12. The Parkway Belt Planning and Development Act
13. The Niagara Escarpment Planning and Development Act

Section 3 of the Planning Act enables the province to clarify provincial policies in matters affecting land use planning through the issuance of policy statements. The purpose of policy statements is to enable the province, from time to time, to set down its objectives on matters of planning concern that apply beyond any one individual municipality. The statements should assist municipalities in understanding what specific provincial objectives are, and will form part of the framework within which municipalities should plan.

Section 3 of the Planning Act requires that municipalities, in carrying out their own planning functions, "have regard to" these statements. At the same time the O.M.B., provincial ministries and agencies are also required by the legislation to "have regard to" such statements in carrying out their varied responsibilities.

Depending on the nature of the particular provincial concern, policy statements may be initiated by the Minister of Municipal Affairs alone, or jointly with other ministers whose responsibilities affect local planning. The Planning Act requires that before a policy statement is approved, the Minister confer with those who are considered to have an interest in the matter.

2.2 The Formulation and Approval of Official Plans

An Official Plan is a comprehensive statement containing objectives and policies established primarily to provide for the physical development of a municipality or an area that is without municipal organization. Most plans comprise maps and a text. One of the maps is usually a land use plan showing where residential, industrial and agricultural uses are expected to locate. The text outlines development policies pertaining to the land use designations on the map. The official plan must be reviewed by Council once every five years.

Official Plans are approved by the Minister of Municipal Affairs or its delegated authority. The Official Plan provides the policy framework for zoning by-laws, plans of subdivision, consents to sever, minor variances, and programs such as capital works. All lower-tier or local Official Plans must conform to the applicable upper-tier

plan, i.e. regional, county, metropolitan or district municipality official plan.

As background to its Official Plan, a municipality would normally do an inventory and analysis of the natural environment to help it determine the ability of the planning area to support various land uses. In order to review and provide comments on land use planning matters, the Ministry of the Environment will require that adequate environmental information is provided on the matter.

As a guide, an Official Plan should contain a section on environmental policies. These policies should include general environmental quality and protection objectives policies based on the physical conditions (natural environment) of the planning area. In other sections of the Official Plan, it is desirable that somewhat more specific environmental policies be included to indicate where the general environmental policies apply. For example, a section on transportation should include policies for the evaluation and control of noise. However, the inclusion of noise policies in specific sections of the Official Plan may vary from municipality to municipality.

The proposed Official Plan must be adopted by the municipal council before it can be submitted to the Minister of Municipal Affairs or the delegated authority for approval. Following submission, the Official Plan is circulated to other Ministries and agencies for their comments. The purpose of this circulation is to identify any conflicts with policies, programs and objectives of Provincial Ministries and agencies.

Comments made by the Ministry of the Environment on the proposed Official Plan, in common with those made by other

ministries and agencies are advisory only. The decision as to whether or not the Official Plan is approved, as submitted or as modified, is made by the Minister of Municipal Affairs or the delegated authority. Modifications may be required or imposed by the Minister as a result of the advice received and recommendations of the staff. The whole, or part, of a proposed Official Plan may be referred by the Minister of Municipal Affairs to the O.M.B., for arbitration. Staff from different Ministries and agencies can be subpoenaed to appear as expert witnesses before the Ontario Municipal Board under the powers of the Ontario Municipal Board Act. Except where a matter has been declared of provincial interest by the Minister of Municipal Affairs, the O.M.B. has the final say in all community planning decisions in Ontario, which have been referred to it. Where a planning matter has been designated by the Minister of Municipal Affairs to be of provincial interest, the Ontario Cabinet reviews the matter, and may confirm, vary or reject the O.M.B.'s decision.

2.3 Amendments to the Official Plan

Official Plans are the basis for successive and more detailed steps in the municipal planning process. However, due to the changing needs and priorities of certain municipalities, amendments to the Official Plan are often necessary after approval of the Plan. Official Plan amendments may make minor changes to the Official Plan, or may propose major policy changes. Once approved, Official Plan amendments become part of the Official Plan.

The approval process of the amendments to the Official Plan is the same as for the Official Plan.

2.4 Municipal Zoning By-Laws

A zoning by-law is a precise document used by a municipality to regulate the use of land. While Official Plans set out the general, long-range policy framework for future land use, zoning by-laws put those plans into effect and provide for their day-to-day administration.

Unlike the Official Plan, the Zoning By-Law contains very specific and legally enforceable regulations. Any new development or construction that fails to comply with a municipality's by-law is not permitted and would be denied a building permit.

Most municipalities have a comprehensive zoning by-law that divides the entire municipality into land use zones. A detailed map of these zones forms an important part of the written by-law. Within each zone, the by-law specifies the permitted uses (e.g. commercial or residential) and the required standards (e.g. location and size of buildings).

A number of specialized by-laws may be used to control land use. Holding by-laws set out the future use of land or buildings but delay their development until, for example, local services such as sewers and water supplies are in place. Interim uses are usually specified. Before being able to use holding by-laws, municipalities must have appropriate Official Plan holding policies in place. Interim control by-laws are used to place a temporary "freeze" on certain land uses while the municipality is studying or reviewing its land use policies. Such a freeze can be put in place for a year at a time, to a maximum of two years only. Temporary use by-laws zone land or buildings for a specific use for a maximum of three years at a time, with further extensions possible.

Increased height and density by-laws allow specific bonuses beyond the standards otherwise permitted, but apply only to developments that provide special facilities or services to the community at large, such as additional parkland or daycare facilities. Before being able to use these by-laws, municipalities must have appropriate Official Plan policies in place, authorizing increases in height or density.

When a municipality decides to prepare a zoning by-law, it must first make adequate information available to the public. Local councils must hold at least one public meeting to allow citizens an opportunity to express their views before a decision is made. Notice of this meeting is given in advance, usually through local newspapers or by mail. Anyone present at the meeting has a right to address the proposal.

The local council may also consult with interested agencies, boards, authorities, or commissions before making a decision. The Ministry of the Environment may provide assistance directly to the municipality with regard to portions of the by-law. When full consideration is given to all concerns, council may decide to pass, change or reject the proposed zoning by-law. If changes are made to the proposal, council must decide whether another public meeting is necessary.

If a person's or agency's concerns cannot be resolved at the municipal level, an appeal may be made to the O.M.B.. A specified period of time from the date of the council decision is available to make your appeal. The O.M.B. will hold a public hearing at which an opportunity will be available to present the case.

The O.M.B. can either allow or dismiss the appeal, repeal or amend the by-law in any way it sees fit. The O.M.B.'s decision is final, except when the Minister of Municipal Affairs declares a provincial interest in the by-law. In this case, the Ontario Cabinet may confirm, overturn or change the O.M.B.'s decision.

2.4.1 Site Plan Control

Site plan control by-laws are not zoning by-laws. They are used by municipalities to establish areas where site plan control will be applied to complement and refine local zoning. These areas must be described in each community's Official Plan. Site plan control is used to ensure that proposed developments are built and maintained as approved by local councils; set requirements for the quality and appearance of new developments; ensure safe and efficient access for vehicle and pedestrians; ensure adequate provision of certain facilities, such as parking, landscaping and site drainage; and protect adjacent properties from incompatible new development.

2.5 Draft Plans of Subdivision

Draft plans of subdivision are submitted by the applicants, who are usually the owners of the land to be subdivided, or their agents, to the Ministry of Municipal Affairs or a municipality which has been delegated the Minister's approval powers. Subdivision approval has now been delegated to all regional municipalities in Ontario. Prior approval by the local or area municipality in which the lands lie is not mandatory.

The Ministry of Municipal Affairs or the delegated authority circulates draft plans to those ministries and agencies whose advice is required in order to evaluate the

draft plan. The local or area municipality is included in this circulation. The draft subdivision plan will be reviewed for suitability; checked against the Official Plan and Zoning By-Laws; considered in light of topography, road access, water availability, sewage disposal, flood control, effect or quality of subsurface water or nearby streams or lakes, noise and other factors.

As with proposed Official Plans and amendments, the Regional MOE offices act as co-ordinators of comments with regard to draft plans of subdivision. The details of the review process are discussed in Chapter 14.

Draft approval amounts to a commitment to go ahead with the subdivision, once all the conditions of draft approval have been met. Lots may be offered for sale after draft approval, but can be sold only after the plan of the subdivision has been registered. When all the conditions of the draft approval has been met, final approval is given and the plan of subdivision is registered in the provincial land titles or registry system.

In most cases of approval of draft plans of subdivision, the developer may be required to enter into a Subdivision Agreement with the municipality to ensure that certain services, such as noise control measures, sidewalks and roads, are provided after the plan has been registered. The Subdivision Agreement may be registered on the title of the property and legally binds future owners to its conditions.

An individual or agency can request the Ministry of Municipal Affairs to refer any unresolved concerns to the O.M.B. for arbitration.

2.6 Building Permits

It may happen that detailed noise control measures cannot be included in the Subdivision Agreement. One reason for this may be that no detailed plans or specifications are available for the residential (or commercial and office) buildings themselves. In this case, it is often possible to include a clause in the Subdivision Agreement which states that the developer/builder is required to have the acoustical consultant certify that the drawings comply with the building specifications (for noise) prior to the issuance of the building permit. The municipality is responsible for issuing a building permit and it is the applicant's formal permission to begin construction. Through the use of building permits, a municipality can regulate the types of construction in the community and ensure that proper building standards are met.

2.7 The Condominium Act

Condominiums are a form of property ownership in which title to a unit, such as individual apartment in a highrise building, is held by an individual together with the share of the rest of the property, which is common to all of the owners.

Condominiums can involve a new development, or an existing rental project which is converted to condominium ownership. They can apply to any type of residential building as well as commercial and industrial areas. Vacant lands are not eligible.

The condominium plan is like a plan of subdivision in that it is a way of dividing property. Similarly, the process for condominium plan approval resembles a plan approval for subdivisions, and must be approved by the Minister of

Municipal Affairs or the delegated authority. However, condominiums may be built prior to final approval, bearing in mind the conditions of draft approval. Condominiums are registered after the buildings are constructed.

Condominium conversions in a number of municipalities are governed by Official Plan policies dealing with the local rental vacancy rates, as well as other matters. Condominium conversions are approved by municipalities.

CHAPTER 3

ACOUSTICS

1.0 NATURE OF SOUND WAVES

1.1 Description of Sound

If a person claps his hands, or strikes a hammer or plays a violin, sound is produced. Sound is an auditory perception of a disturbance which travels or propagates in the form of waves similar to waves in water.

For the sound to travel or propagate the surface must be in contact with a material medium such as air, water or a solid. Sound cannot propagate in vacuum.

A familiar sight is waves travelling across the surface of water. The action of the water particles is simply to bob up and down like a cork and not to move with the wave. In sound waves the particles of the medium simply oscillate to and fro in the direction of the wave, but again do not actually travel with the wave. The energy in the wave is transferred to more distant parts of the medium by a "chain" reaction.

1.2 Sound Pressure

Consider a loudspeaker generating sound as shown in Figure 3.1. It does so by the to and fro motion of a diaphragm which in turn transmits this motion to the air adjacent to it. This results in small fluctuations in air pressure which travel outwards. These fluctuations in pressure are picked up by the ear as sound. Note that

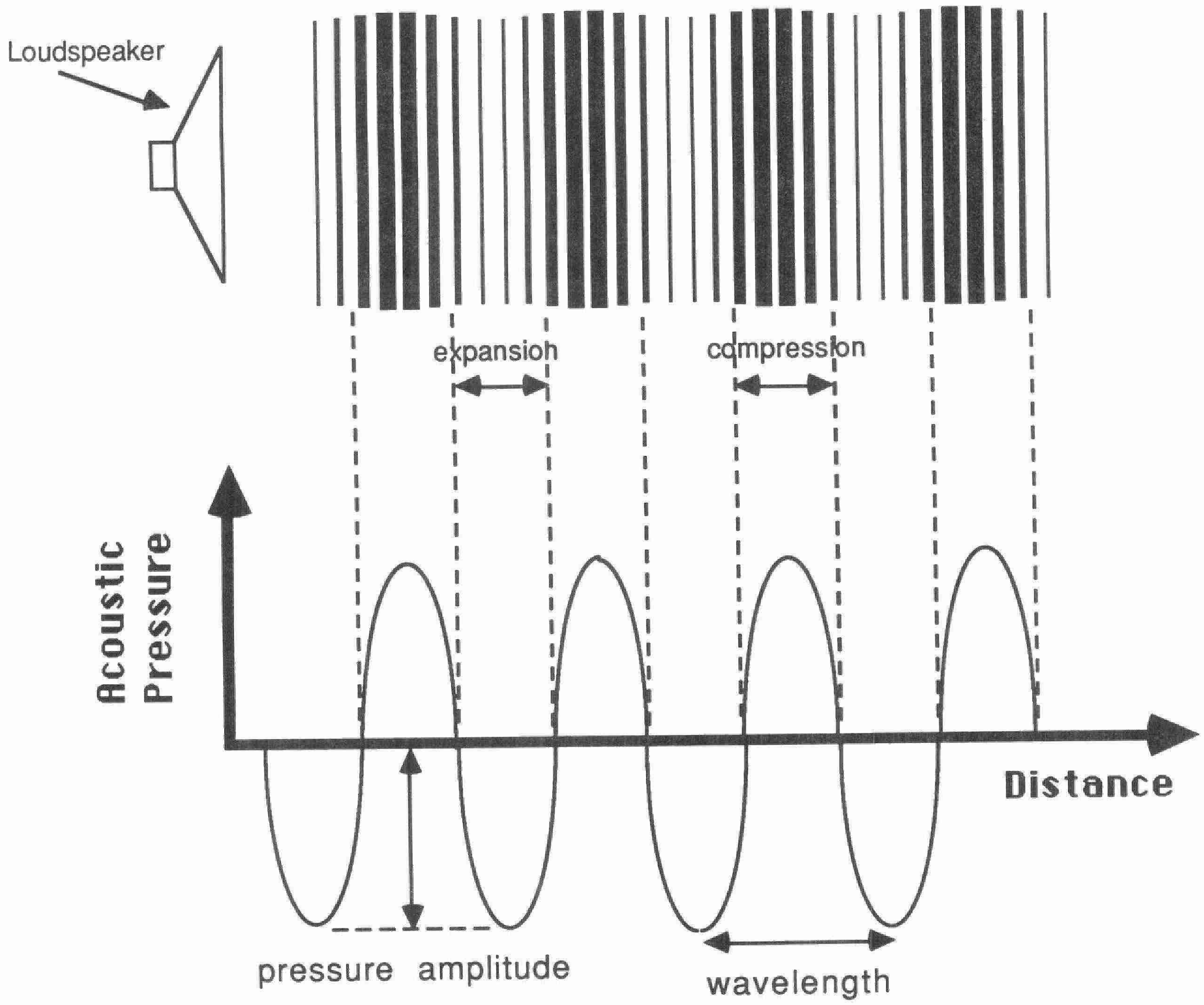


Figure 3.1. Generation of sound waves

this pressure fluctuation due to sound is superimposed on the normally existing barometric pressure. The additional pressure due to sound is very small compared with the normal barometric pressure.

This to and fro motion causes alternate compression and expansion of the air. These pressure fluctuations are sensed by the ear as sound.

1.3 Speed of Sound in Air

Sound waves do not travel instantaneously. Their speed depends on the medium through which they travel. The speed of sound in air is related to atmospheric temperature, and at 20°C the speed of sound in air is approximately 344 m/sec.

Example

Although lightning and thunder are generated simultaneously during a thunderstorm, the observer first notices the lightning and only later hears the thunder. The delay is caused by the time needed for the sound to travel from the thunderstorm location to the observer. (The light due to the lightning can be considered to travel the distance almost instantaneously.)

1.4 Sound Power

Sound power is a basic measure of the acoustic output of a noise source. The sound pressure produced by the source depends on many external factors such as distance and orientation of the receiver, the temperature and velocity gradients in the medium and the environment. Sound power on the other hand is a fundamental physical property of the acoustic source alone and is, therefore, an important

absolute parameter which is widely used for rating and comparing sound sources.

Sound power is expressed in "watts".

2.0 FREQUENCY, WAVELENGTH AND SPEED OF SOUND

2.1 Frequency

Consider the earlier example of the loudspeaker (refer to Figure 3.1). When the diaphragm of the loudspeaker moves to and fro this generates pressure fluctuations in the air adjacent to it in the form of sound waves.

The number of times every second the air experiences these pulsations or fluctuations is known as the "frequency of the sound waves".

Obviously the frequency of the sound waves generated is the same as the frequency at which the diaphragm moves to and fro.

The frequency of sound waves is expressed in "cycles per second". Cycles, in this case, refer to the pulsations of air due to sound waves. In noise control work a more commonly used unit is "hertz" (Hz). "Cycles per second" and "hertz" are the same.

Example

If the loudspeaker diaphragm moves to and fro 125 times every second continuously, the frequency of sound waves thus generated will be 125 cycles per second or 125 Hz.

All sounds can be related in terms of frequencies. Generally most of the every day sounds are a mixture of different frequencies, and the human ear is capable of detecting sounds in the approximate frequency range 15 Hz to 15,000 Hz (or 15 kHz). The ear's sensitivity is not uniform or "flat" over this range, the sensitivity reducing rapidly at the extremes of the frequency range. The sensitivity of the ear to frequency plays an important role in the noise control field.

2.2 Wavelength

The distance between to successive waves is defined as the wavelength. When we talk about the wavelength of a sound wave, we refer to the distance between two successive points, where either the compression or the expansion is maximum (also indicated on the diagram, Figure 3.1). Wavelength is not usually directly measured but can be determined as shown in the following section.

Wavelength can be calculated from a knowledge of the frequency and the speed of the sound. It is given by the following relationship:

$$\text{wavelength} = \text{speed of sound}/\text{frequency} \qquad (3.1)$$

If the speed of sound is expressed in metres per second, and the frequency in Hertz, the wavelength will be in metres.

Example

In air, the speed of sound at 20°C is 344 m/sec.

For a frequency of 100 Hz:

wavelength in metres = 344/100 = 3.44 m

For a frequency of 500 Hz:

wavelength in metres = 344/500 = 0.688 m
= 68.8 cm

It is to be noted that the sound frequency increases as wavelength decreases.

When measuring sound in the immediate vicinity of sound sources outdoors, a knowledge of wavelength helps in selecting the best measurement locations. The distance between measurement location and the source should ideally be much larger than the wavelength corresponding to the frequency of interest. At the other extreme, high frequency sound (having a short wavelength) is not directly measurable when the diameter of the microphone exceeds the wavelength of the sound. The latter is an example of diffraction of sound, that ability of sound to "bend" around obstacles. The amount of this bending is again related to wavelength, bending increasing with wavelength. This subject is treated in Chapter 9.

3.0 TYPES OF SOUND WAVES

As explained in the previous sections, sound travels in the form of waves. There are basically three types of sound waves:

- Spherical
- Cylindrical
- Plane

The types of wave generated depends upon the sound source. The sound waves from a loudspeaker at a distance of about 15 m will be of the spherical type. On the other hand, when we think of the noise from freely flowing traffic on a highway, the noise comes from a very large number of (moving) point sources. It can be shown that the sound from a whole string of point sources gives rise to waves which spread in a cylindrical fashion, the line or string of sources, being the axis of the cylinder. At very large distances from a source (very large in comparison to the size of source) spherical and cylindrical waves are very similar to plane waves and may be considered as such. Examples of spherical and cylindrical waves are shown in Figure 3.2.

4.0 LOGARITHMIC SCALE: DECIBELS

4.1 Range of Sound Pressure Values

The ear can respond to an amazingly wide range of acoustic pressures. In everyday life we may encounter acoustic pressures such as generated by rustling leaves and the acoustic pressures of a roaring jet engine. The acoustic pressure of the latter example may be one million times that of the former. In between these two extremes lie all the familiar sounds of modern life, e.g. traffic, bird songs, construction, etc.

While we have discussed acoustic pressure and the response of the ear to it, experience has shown that the square of the pressure is a fundamentally more useful quantity in assessing the magnitudes of sounds. The major reason for this is that the square of the pressure as measured at an

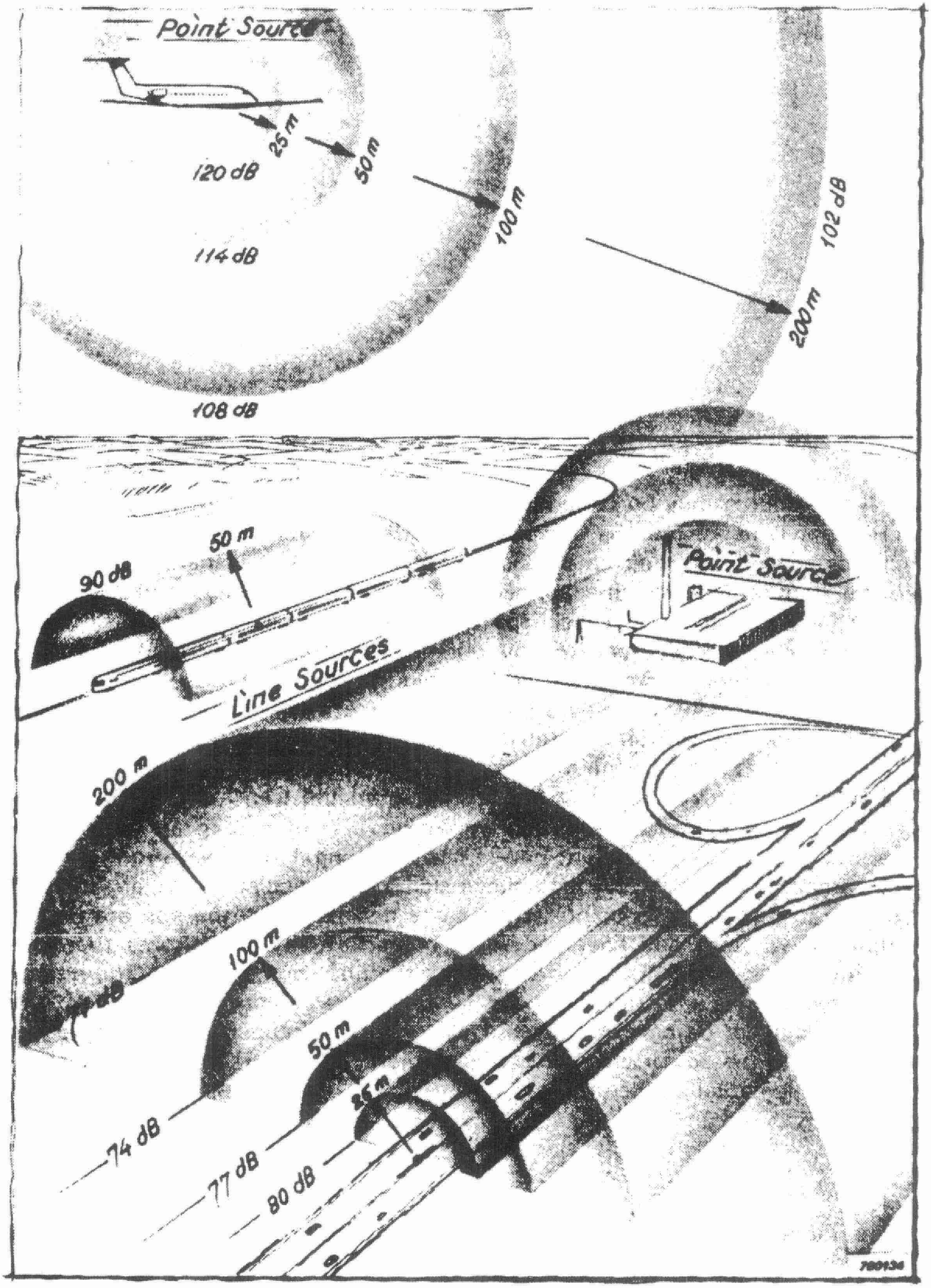


Figure 3.2. Examples of point and line sources

observer is related to the acoustic power of the noise source.

4.2 Decibel Definition

Another reason for adopting "pressure squared" term is that this naturally leads to the use of the decibel scale of measurement. The decibel scale is widely used in various branches of electronics and acoustics. The decibel scale is a power scale and gives a comparison between power related quantities. When quantities are compared using the decibel scale, the comparison is referred to as a Level.

Definition

The Sound Power Level (PWL) or L_W, of a noise source is defined as:

$$L_W = 10 \log [W/W_{ref}] \text{ dB} \qquad (3.2)$$

where W is the acoustic power output of the source in watts, and W_{ref} is the standard reference power of 10^{-12} watts. In all likelihood W will be greater than the very minute value chosen for W_{ref} and so all sound power levels will be a positive number of dB's.

Also, the square of the acoustic pressure is related to the acoustic power output so we may now define SPL, or L_P, at some observer as:

$$L_P = 10 \log [P^2/P^2_{ref}] \text{ dB} \qquad (3.3)$$

where, P is acoustic pressure of the sound waves, in microPascals, μPa and P_{ref} is the standard reference pressure of 20 μPa.

4.3 Relationship Between SPL and PWL

The PWL is a measure in decibels of the sound power output by a source. This sound power will radiate away from the source in all directions. As the sound waves travel away from the source the pressure fluctuations must decrease because the available sound power is being spread over a larger area (see Figure 3.2).

A similar situation exists when a balloon is being blown up. The bigger the balloon becomes the more the rubber is obliged to stretch and the thinner it becomes. The sound pressure fluctuations are "diminished" and reduced in a similar manner as the available sound power is spread over a larger and larger surface area. The sound power output itself remains constant whatever the distance from the source. The sound pressure fluctuations decrease according to the area over which the available sound power has been spread. Thus the relationship between the sound pressure level, L_p, and the sound power level, L_W, in most simple situations can be expressed as follows:

$$L_p = L_W - 10 \log S \qquad (3.4)$$

where, S is the total surface area in m^2, over which the sound power is spread. We can now take this equation further for the two main types of source.

4.3.1 Point Source

A point source can be imagined as being a point suspended in air radiating sound equally in all directions. Let us consider an observer at a distance r from this point source of sound power W with no reflecting surfaces present.

First, $S = 4\Pi r^2$ (i.e. the area of a sphere of radius r). Let us also consider the effect of increasing r on the sound pressure level.

Let L_{P1} be the Sound Pressure Level at distance r_1

and L_{P2} be the Sound Pressure Level at distance r_2

Then $L_{P1} = L_W - 10 \log [4\pi r_1{}^2]$

$$L_{P2} = L_W - 10 \log [4\pi r_2{}^2]$$

$$L_{P2} - L_{P1} = 10 \log [4\pi r_1{}^2 - 4\pi r_2{}^2]$$

Thus, for a point source

$$L_{P2} - L_{P1} = 20 \log [r_1/r_2] \qquad (3.5)$$

From this equation it can be seen that if the distance from a point source is doubled, the sound pressure level is reduced by 6 dB.

4.3.2 Line Source

A line source can be imagined as an infinitely long line suspended in the air radiating sound equally in all radial directions. A similar procedure can be followed as for a point source to obtain the relationship between sound power level and sound pressure level for a line source. However, this involves integration techniques and will not be considered here. Only the effect of increasing r on sound pressure level will be considered.

Again let

L_{P1} be the sound pressure level at distance r_1

and L_{P2} be the sound pressure level at distance r_2.

Thus, for a line source

$$L_{P2} - L_{P1} = 10 \log [r_1/r_2] \qquad (3.6)$$

From this equation it can be seen that if the distance from a line source is doubled the sound pressure level is reduced by 3 dB.

Example

A sound level of 65 dB was measured at a distance of 10 m from a line source. The sound level at 30 m is required.

Let $L_{P1} = 65$ dB measured at $r_1 = 10$ m

then from equation 3.6 (for a line source)

$$L_{P2} - L_{P1} = 10 \log [r_1/r_2]$$

$$L_{P2} - L_{P1} = 10 \log (10/30)$$
$$= -4.8 \text{ dB}$$

$$L_{P2} = 65 - 4.8$$
$$= 60.2 \text{ dB}$$

4.4 Advantage of the Decibel Scale

The decibel scale is commonly used in electronics and acoustics for the measurement of power related quantities.

An advantage of the decibel scale is that the unwieldy numbers which result from using a linear pressure scale are replaced by a much smaller range.

Another feature of the scale is that for each and every tenfold increase in power, the SPL at an observer increases by 10 dB. If we should increase the power output from 10^{-12} W to 10^{-11} W or from 1 W to 10 W we would, in each case, get an increase of 10 dB. Although the actual change or absolute change in power output in the two cases is quite different, we get the same change in decibels. This is actually of value because if we listened to these changes in level, approximately the same subjective response would be obtained - we would say that in each case the noise had doubled in loudness from its former value. That is, the increase in loudness appears the same.

The sound pressure levels and sound power levels of various types of common noise sources are shown in Figures 3.3 and 3.4.

4.5 Weighting Networks

It was pointed out in Section 2.0 that the ear's response to sound is not linear over the audible frequency range (15 Hz - 15,000 Hz). In addition, the ear's response depends on the sound level.

In order to satisfactorily describe human perception and response to sound, the sound is usually filtered or weighted across frequencies in a manner analogous to spectral response characteristics of the ear. The weighting networks that are currently in use are shown in Figure 3.5. The weighting network commonly fitted with SLMs used for acoustic measurements in land use technology is the A-weighting. The sound pressure level after being weighted by the A-network is commonly referred to as dBA. (If the sound pressure levels are taken with linear response, the values are quoted in dB.)

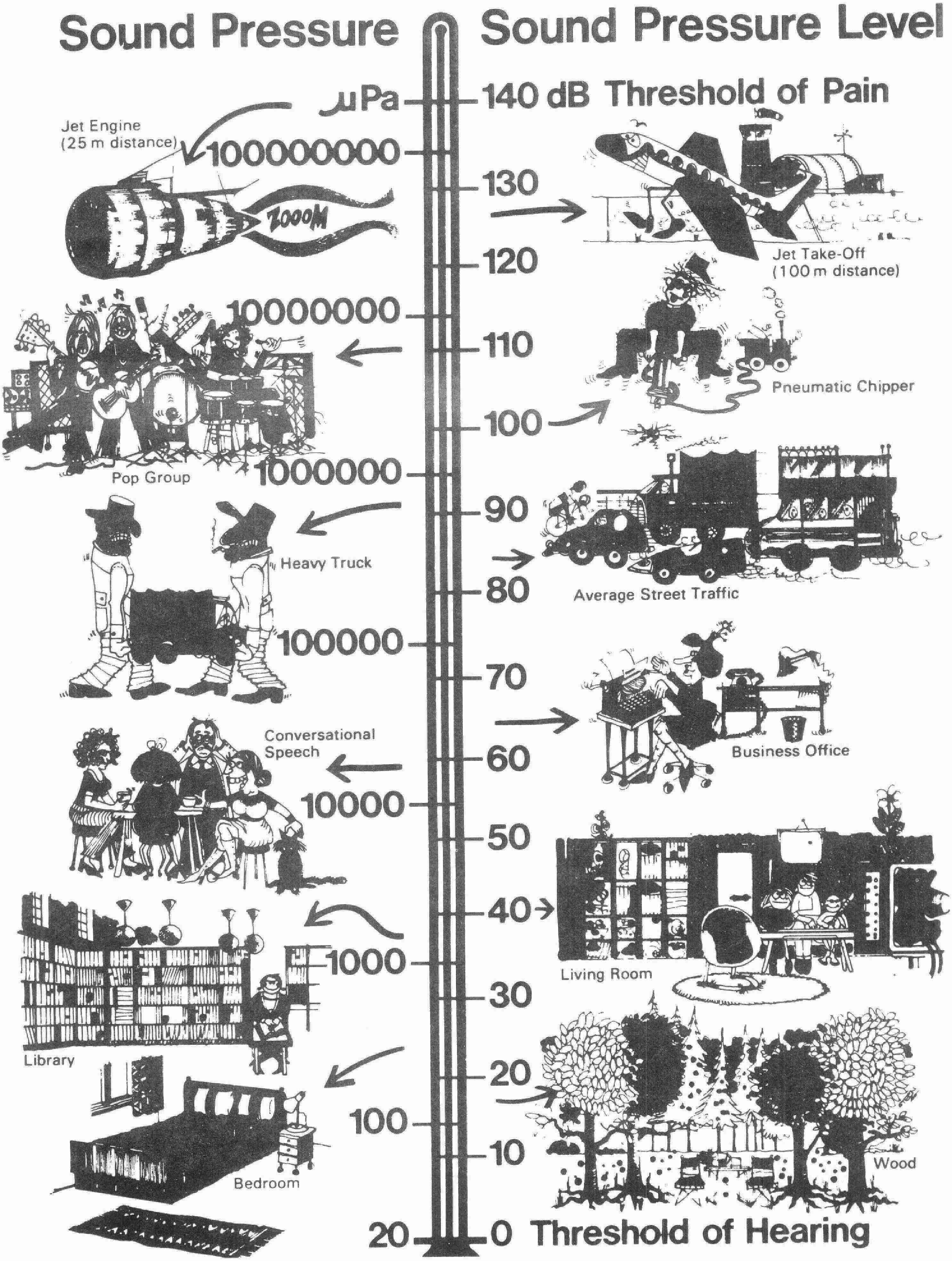


Figure 3.3. Typical sound pressure levels (SPL)

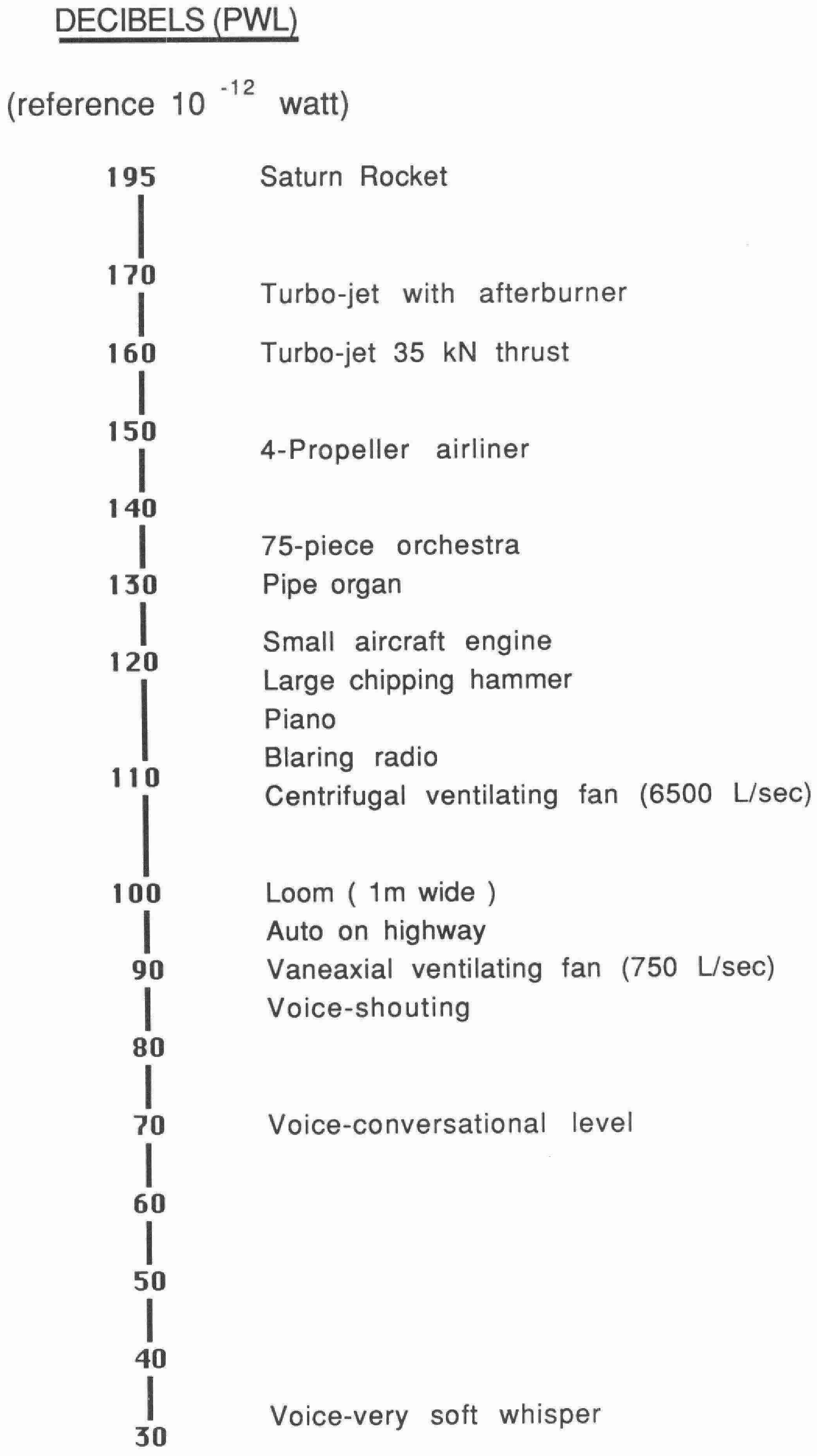


Figure 3.4. **Typical sound power levels (PWL)**

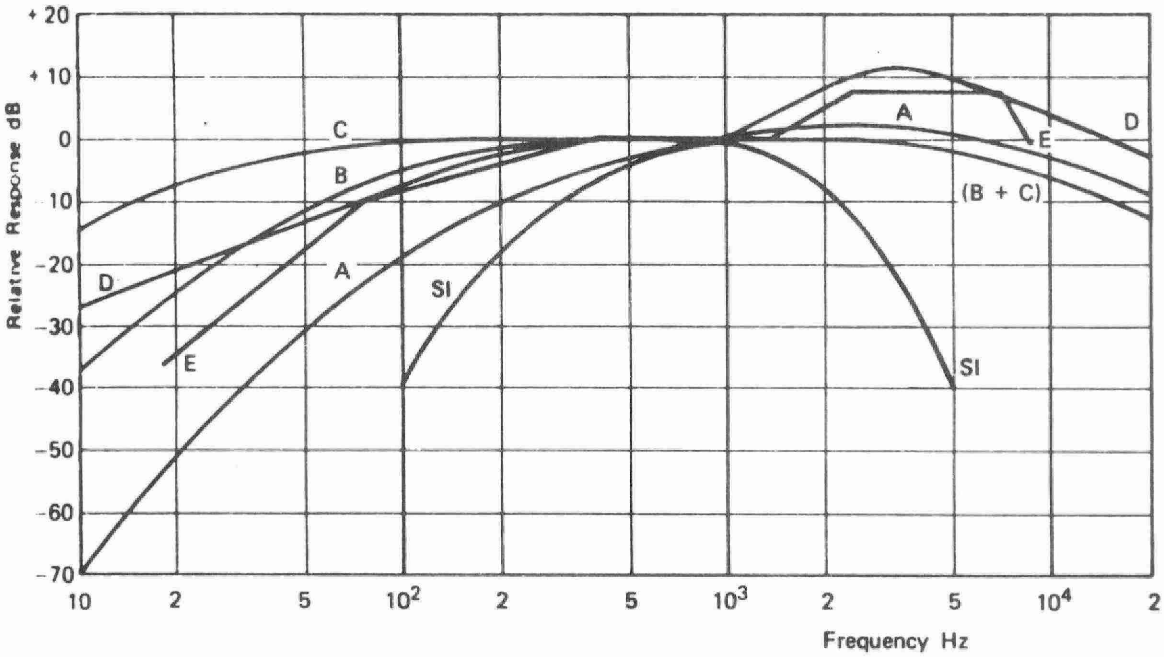


Figure 3.5. The internationally standardized weighting curves for sound level meters and recently suggested E and SI weighting

4.6 Sound Level Meter

Sound pressure levels of common noise sources can be conveniently measured with an instrument called a sound level meter. Details of acoustic instrumentation are presented in Chapter 11.

Briefly, a simple sound level meter measures the "linear sound pressure level" in dB and the "A-weighted sound pressure level" in dBA. It also uses two averaging time weighting characteristics; fast and slow.

4.7 Adding Sound Pressure Levels in Decibels

SPLs cannot be added rather they must be combined. This is because when sounds from separate sources are received

simultaneously the ear responds to the sum of their individual power contributions and not to the sum of their pressures (or sound pressure levels in dB). Therefore, as we are usually given the SPL of each source in turn (in dB), conversion to pressure squared terms must be done first. This involves finding the antilog of 1/10 of the SPL. Ten times the logarithm of the sum of such antilog terms gives the resultant SPL of the combined levels. In mathematical notation:

If sound pressure level due to Source 1 is L_{P1}
If sound pressure level due to Source 2 is L_{P2}
If sound pressure level due to Source N is L_{PN}.

Then it can be shown that the resultant SPL, L_{PR} is;

$$L_{PR} = 10 \log [\text{antilog} [L_{P1}/10] + \text{antilog} [L_{P2}/10] + \ldots + \text{antilog} [L_{PN}/10]] \quad (3.7)$$

This expression may be used to combine the SPLs due to two or more sources, etc.

4.7.1 Addition of Decibels - Nomograph Method

The nomograph given in Figure 3.6 provides a quick, simple and practical method for combining pairs of decibels. The steps involved are outlined below:

Step 1: Take the difference in decibels between the two levels which are being added together.

Step 2: Enter this difference on the chart at the right hand side of the scale, and look up the corresponding number on the left hand side of the scale.

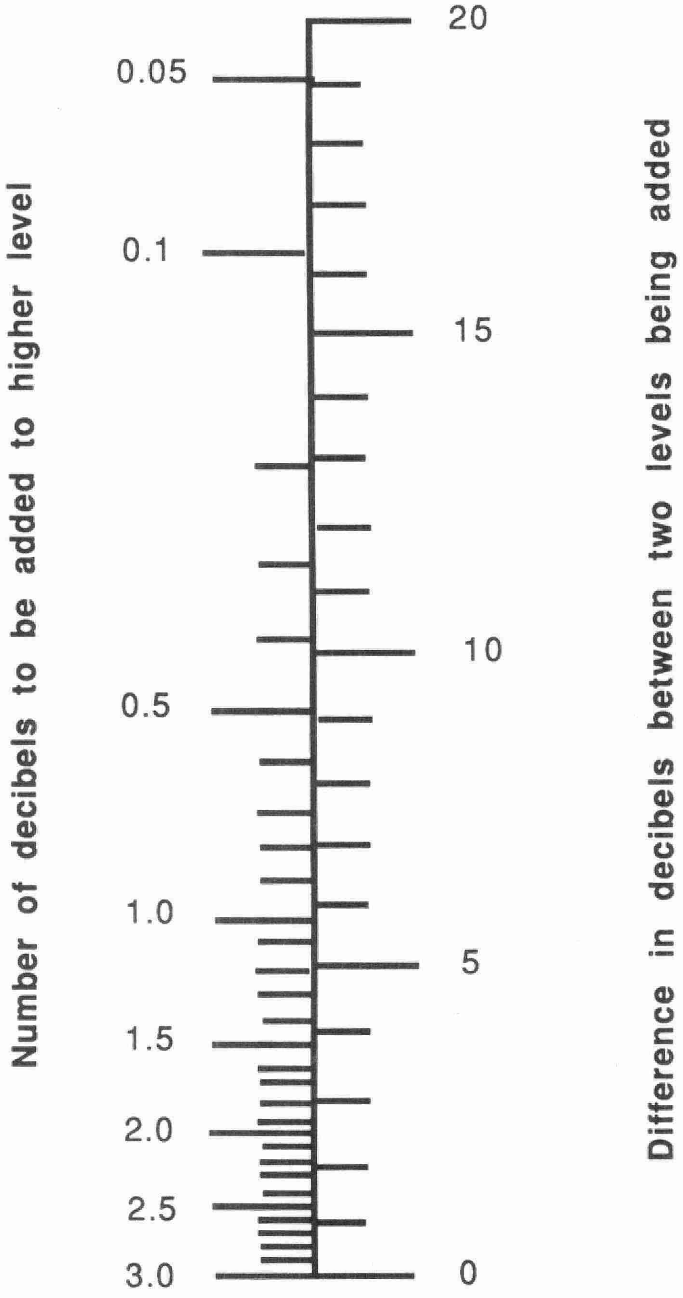


Figure 3.6. Nomograph for adding sound pressure levels in decibels

Step 3: Add the number so obtained to the higher sound level (louder sound of the two).

Should more than two SPLs need to be combined, then any two levels can be replaced in the summation by their equivalent found by the combination process.

Example

Find the resultant of the following sound pressure levels 60 dB, 54 dB and 65 dB.

Consider first 60 dB and 54 dB.

Step 1: the difference is 6 dB
2: from the chart the corresponding number is about 1 dB
3: adding 1 to the higher SPL we get 61 dB

So the result of combining 60 dB and 54 dB is 61 dB.

Consider now combining 61 dB (i.e. 60 dB and 54 dB) and 65 dB.

Step 1: the difference is 4 dB
2: from the chart the corresponding number is about 1.5 dB
3: adding 1.5 dB to the higher we get 66.5 dB

So the effective SPL due to the three individual SPLs is 66.5 dB or 67 dB after rounding.

Should the sequence in which the SPLs are combined be changed, the identical result would be obtained.

Note from the nomograph method:

(a) two levels will not result in more than 3 dB adjustment to the higher level;

(b) when two levels are more than 10 dB different, their resultant SPL is less than 0.5 dB greater than the higher of the two levels; and

(c) very roughly, for quick calculations, you may use:

difference between two levels, dB	add to higher level, dB
10	0
6	1
2	2
0	3

which can be memorized and interpolations made by constructing a graph.

CHAPTER 4

VIBRATION CONSIDERATION IN LAND USE PLANNING

1.0 INTRODUCTION

The present document is loosely titled "Environmental Noise Assessment in Land Use Planning", which implies only details dealing with sound will be discussed. However, vibration is also designated as a contaminant by the Environmental Protection Act of Ontario. Vibration is now brought into the realm of land use planning to address the prevention of this contaminant impacting the environment.

The fundamental building blocks (both mathematical and physical) of vibration are very much similar to that of sound even though the control measures are very different. A brief description of the fundamentals of vibration and its behaviour will be presented along the same lines as that of sound in Chapter 3. A few of the important sources of vibration will be outlined. Available procedures for impact assessment will also be presented.

2.0 NATURE OF VIBRATION

2.1 General Description

Vibration is a temporal and spatial oscillation of particles described in terms of displacement, velocity or acceleration in a solid medium. Any moving disturbance produces vibration. Unlike sound, vibration requires the presence of solid medium for its existence, transmission

and perception. Analogously sound can also be called as audible vibrations of air. Some examples of vibrating sources are punch presses, a moving train and any rotating machinery.

Vibration travels in the form of waves from the source to the receiver just like sound. Due to the characteristics of solid medium, vibration travels both as a longitudinal wave as well as a transverse wave, unlike sound which propagates only as a longitudinal wave. One other major difference between vibration and sound is that sound pressure is a scalar quantity whereas vibration is a vector quantity, and hence the direction of the vibration vector is a required quantity when reporting the vibration results.

2.2 Physical Description of Vibration

Vibration is usually generated by physical motion such as heavy footsteps on a long span floor or rotating machinery with a slight imbalance. The reactive motion represents the physical measure of the vibration excitation. Motion is generally described in terms of displacement, velocity (rate of change of displacement) or acceleration (rate of change of velocity). Unlike sound where sound pressure is a meaningful single physical measure, vibration can be described in terms of any of the above three measures. Each one of the three is a valid measure depending on the specific vibration environment. The three measures are closely related to each other. Velocity is the time rate change of displacement and acceleration is the time rate change of velocity. The above relationships are graphically described in Figure 4.1. The axes in the figure are logarithmic.

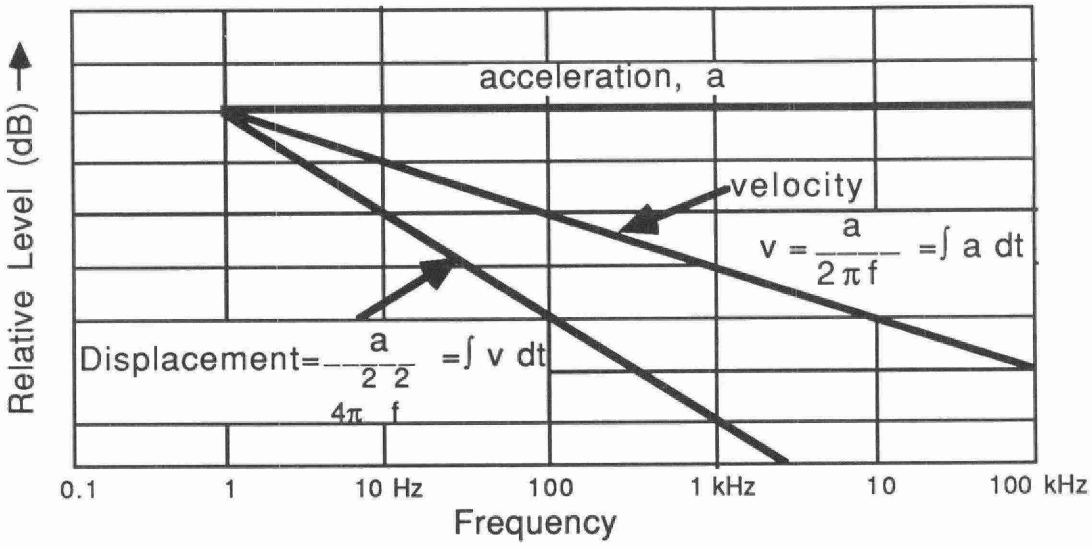


Figure 4.1. The integration and double integration of acceleration to obtain velocity and displacement respectively.

2.2.1 Vibration Descriptor

In theory, it is irrelevant which of the three parameters, acceleration, velocity or displacement are chosen to measure vibration. If one plotted a narrow band frequency analysis of a vibration signal in terms of the three parameters, they would all show the same frequency components but would have different average slopes as seen in Figure 4.1. It can also be seen that displacement measurements give low frequency components most weight and conversely acceleration measurements give more weight to the high frequency components. This leads to a practical consideration that can influence the choice of parameter. It is advantageous to select the parameter which gives the flattest frequency spectrum in order to best utilize the dynamic range of the measuring instrumentation.

The nature of mechanical systems is such that appreciable displacements only occur at low frequencies, therefore, displacement measurements are of limited value in the general study of mechanical vibrations. Displacement is

often used as an indicator of unbalance in rotating machine parts because relatively large displacements usually occur at the shaft rotation frequency, which is the frequency of primary interest for balancing purposes. Displacement is also used to measure seismic vibration as they occur at low frequencies.

Velocity measurements are widely used for vibration "severity" measurements. This is due to the fact that vibratory velocity is simply related to vibratory energy and is, therefore, a measure of the destructive effect of vibration. A given velocity level also signifies constant stress for geometrically similar constructions vibrating in the same mode.

Because acceleration measurements are weighted towards high frequency vibration components, this parameter is preferred where the frequency range of interest covers high frequencies.

The details of the complete vibration instrumentation are given in Chapter 11.

2.3 Logarithmic Scale: Decibels

The variation in vibration values from the threshold of human perception to very high levels is not as pronounced as it is in sound. The usual range is of the order of 5 decades in the case of vibration, whereas sound levels can vary by about 12 to 13 decades. However, a similar logarithmic description is used in vibration measurements. The decibel description and definitions were given in Chapter 3.

The vibration level L_v is defined as;

$$L_v = 20 \log (V_{rms}/V_o), \text{ dB} \qquad (4.1)$$

where V_{rms} is the root-mean-square value of the vibration acceleration

V_o is the appropriate reference value

Generally, used reference value is,

$V_o = 10\mu m/s^2$ for acceleration

2.4 Vibration Propagation

The propagation of sound was described using simple spherical or cylindrical waves as related to point sources and line sources. Vibration also travels in the form of waves. However, propagation of vibration is a complex phenomenon (even in land use assessment) depending on the source type, the solid medium through which vibration is being transmitted and the coupling between the two. The different vibration wave types travel at different wave speeds, from a single source to a single receiver, complicating the issue further. Sound waves travel at a single speed in a given medium (for example, sound speed is 344 m/s in air at 20°C). It is beyond the scope of this manual to discuss in detail the complexities of vibration propagation. Only a brief mention has been made to highlight the complex nature of this physical phenomenon.

2.5 Coupling of Vibration to the Propagation Medium

The importance of coupling will be highlighted by first describing the phenomenon for sound waves.

The main concern in land use planning is to assess sound propagation primarily through air. Once the receiver's location is a few wavelengths away from the noise source, the propagation of sound can be basically described in terms of plane, cylindrical and/or spherical waves as presented in Chapter 3. Terms like decay rate of 6 dB per doubling of distance or 3 dB per doubling of distance can be quite accurately applied. For example, traffic noise from highways has most of the acoustic energy in 500 Hz frequency band. The wavelength in air at that frequency is around 0.7 m. At distances of 10 m or more the sound propagation can be simply interpreted in terms of cylindrical waves with a 3 dB decay rate for every doubling of distance. Such a simple description is not possible in vibration as the propagation characteristics are determined by both the source, the medium of transmission and the coupling between the two. A brief description of the problem is given below.

Propagating medium for vibration is a major parameter of influence. Example of the medium are; the foundation block of a punch press, ground of various soil combinations from a train track to a single family dwelling, a large rectangular plate connecting the floor of a plant to the machine, etc. Unlike a fluid medium (air or water), solid media can vibrate freely if set in motion. Such a motion is called natural mode of vibration. An example would be a pendulum oscillating about its axis. The natural or free vibrations have certain preferred frequencies. A string fixed at both ends, for instance, would have natural frequencies for transverse motion given by

$$f_n = nc/2l, \quad n = 1, 2, 3 \qquad (4.2)$$

where c = speed of the wave in the string
l = length of string

It is seen from equation (4.2) that there are an infinity of free modes of vibrations possible. Similarly each solid medium would have very many natural frequencies at which the medium can vibrate freely depending on its size, shape, support conditions and material properties.

A vibrating source would have many frequencies depending on the operating conditions. For example, a slightly unbalanced rotor would have unbalanced forces excited at frequencies which are multiples of rotor RPM. If any of the frequencies excited by a vibrating source matches with any of the natural frequencies of the propagating medium, resonance condition is on-set. Under conditions of resonance the amplitude of excitation by the source is usually amplified (sometimes by factor as high as 10 to 20). The amplification factor depends upon the elastic properties of the medium. In some instances amplified vibration amplitude can be high enough to cause structural fatigue. Usually under conditions of resonance the medium does not attenuate the vibration and hence the motion can be transmitted from the source to the receiver without reduction. Under non-resonance conditions the medium would attenuate the vibration motion in addition to the reduction due to wave spreading if applicable. It is seen that vibration propagation is complex, very much dependent on site specific conditions and careful field study is needed for proper evaluation.

3.0 EVALUATION OF VIBRATION IMPACT

Vibration impact is usually evaluated in terms of human response to building vibration. The first step is then

to prescribe the vibration limits that are acceptable in a building from a human annoyance point of view. A number of guideline documents relating to human response to building vibration has been published (most of them in draft form) to date. The majority of the documents address human response to continuous vibration. Impulse vibration impacts produced by sources such as punch presses and infrequent events such as train passbys are not well understood. Several different approaches and suggested limits as well as only sketchy description of measurement procedure and instrumentation can be found in state-of-the-art documentation. Two such documents are listed in the Bibliography.

The vibration levels from a given source are established either through prediction or through measurements at the sensitive receptor location. Prediction of vibration level from a source is usually not very accurate and is dependent on various parameters, many of them not easily obtainable for land use planning purposes. In most instances the use of measurement procedures may be the only recourse in establishing the vibration levels.

If the sensitive location is within a building the levels can be directly compared to acceptable criteria and impacts can be evaluated. However, in land use compatibility assessment measurements are usually conducted on the ground where a particular sensitive building is to be constructed. The relationship between the outside level and the expected level inside the proposed building must be established. Unfortunately such a relationship is another complicated phenomenon, depending on soil conditions, building type and factors that control the coupling between the soil and the building. The building vibration level can vary from twice as large to smaller than the outside level. It is seen that vibration assess-

ment is a complicated process depending on site specific conditions.

Three common sources of vibration impact and corresponding assessment procedures are outlined below. It must be pointed out that the list is not exhaustive, however, any vibration source can be analysed in similar fashion as to their impact. The first two are examples of sources that produce vibrations that are impulsive in nature and the third one is an example of a source that generates continuous vibration.

3.1 Assessment of Blasting Vibration

Blasting is used in quarrying and surface mining to fracture and separate various rock materials for easy handling and further processing. Excavation, preparation of foundations and trenching of sewage and water lines or other service or transmission lines running under the surface of the ground also, from time to time, requires the assistance of blasting. One of the unpleasant side effects of blasting is ground vibration.

Ministry publication NPC-119 sets the limits for ground borne vibrations due to blastings. NPC-119 has been revised and a draft guideline procedure to assess vibration was issued in 1985. The draft publication is listed in the Bibliography.

3.2 Assessment of Impulse Vibrations

Impulse vibration can be caused by the operation of a number of industrial sources such as punch presses, stamping presses, drop forges, etc.

A new draft publication has been prepared by the Ministry to evaluate the impact of industrial sources. The draft publication is listed in the Bibliography.

3.3 Assessment of Railway Vibration

Available land for sensitive uses is becoming scarce in metropolitan areas. As a result, more and more sensitive developments are being built close to major train tracks, and accurate impact assessment of new sensitive land uses beside railway lines is required.

The impact of ground-borne vibration due to railway operation is yet to be defined and hence a position paper addressing all the aspects of vibration impact is required. The staff of the Ministry of the Environment are working on the various details at the present time. The position paper would be formulated along the following lines.

3.3.1 Draft Railway Vibration Assessment Procedure

The procedure deals with the assessment and mitigation of the impact of ground-borne vibration from train passbys in the case of sensitive developments that are to be built next to railway lines. The guidelines of the draft procedure are presented in this brief summary.

3.3.1.1 Red-Flagging

The red-flagging procedure is used when a sensitive development may be impacted by train vibrations. A proposed development is red-flagged if: (a) it is within 40 m of the right-of-way of a railway line and (b) if the

railway line is a principal main line, a principal branch line or a secondary main line.

If a development is red-flagged, then the developer must prepare a train vibration assessment report.

3.3.1.2 The Train Vibration Study

(a) The instrumentation used for the study must be capable of measuring and analysing vibration velocity or ground acceleration caused by the trains.

(b) The measurement procedure requires the measurement of outdoor ground vibration through suitable (and acceptable) mounting means. The measurement location would be along the line of the closest building structure to the railway track. Measurement at preset locations must be used. Ground vibrations from a preset number of train passbys under normal operating conditions including at least a few freight trains must be measured.

(c) The recommended vibration criterion level is 6 dB below the attached ISO (International Standards Organization) curve (see Figure 4.2). The maximum RMS level out of the five measurements is to be compared with the recommended criterion.

(d) If the measured level exceeds the criterion, then control measures should be investigated and addressed in the report.

(e) The report should include a description of the site, instrumentation system used, calibration procedure, measurement locations, train traffic information, data on the measured trains, a comparison of the

measured maximum level with the recommended criterion and proposed control measures.

3.3.1.3 Mitigation Measures

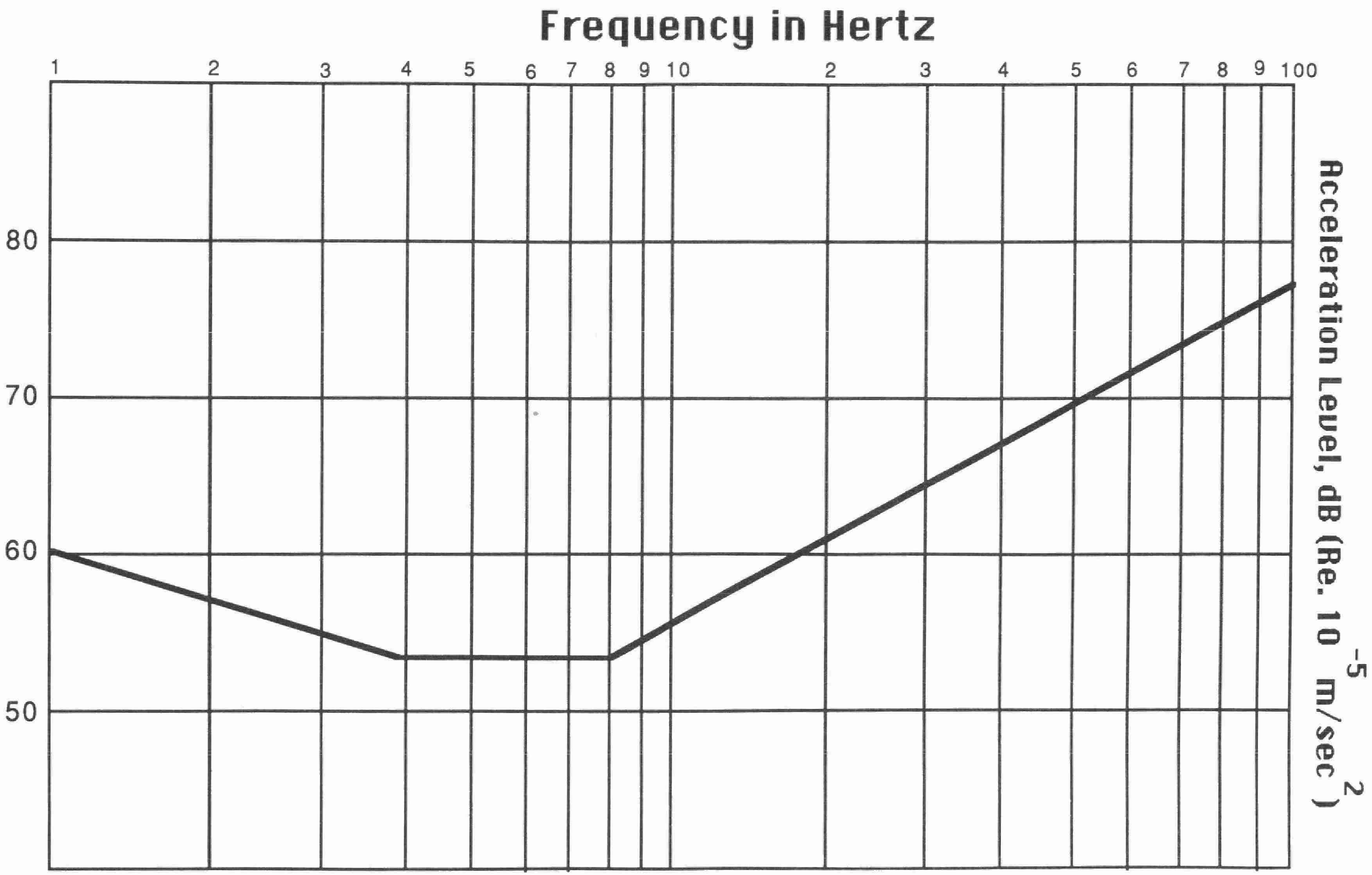
If the outside measured vibration level exceeds acceptable criteria, mitigation measures are required. Three alternate measures are available at this stage. One or more may help to resolve or minimize the vibration problem:

(a) Distance setback

(b) Isolation techniques; isolation could be applied either to the building or to the ground; building isolation should be designed in consultation with the architect and the structural engineer.

(c) Warning clause

*Note: It must be pointed out that the procedure described in Section 3.3.1 is not the policy but a draft outline on which the details would be formulated.



(NOTE: diagram is not exactly to scale)

Figure 4.2 ISO threshold of perception for continuous vibrations (measured in 1/3 octave bands)

CHAPTER 5

ANALYSIS OF COMMUNITY NOISE

1.0 INTRODUCTION

The assessment of noise impact of proposed projects or actions necessitates the acquisition of a number of critical pieces of information. The different pieces of information are used in judgements and decisions regarding associated costs versus benefit, the degree of noise control desired and the feasibility of noise mitigating techniques. In the field of community noise analysis the required information is usually centred around the physical attributes of sound.

The main objective of noise analysis is to relate the physical attributes of the noise environment to measures of human response or criteria of acceptability. Many of the physical attributes and measures of sound were outlined in a previous chapter. The useful relationships between the physical exposure and noise impact are usually obtained by measurements, computation and by the use of various noise descriptors. A noise descriptor is a physically measurable quantity such as Sound Pressure Level in dB and the descriptor is used to scale the impact numerically.

The community noise impact can be described by a variety of descriptors. One such descriptor is presented in this chapter. The rationale for choosing the descriptor, the definition of the descriptor and its applications are also presented.

2.0 THE TIME VARYING NATURE OF COMMUNITY NOISE

Many community noise sources do not produce noise of a steady nature. Noise sources such as traffic, construction sites and radios produce noise levels which are time-varying, often in a very wide range. The fluctuating nature of the community noise is evident in a continuous record of the sound level as illustrated in Figure 5.1. The figure represents a time history, i.e. the sound levels are recorded as a function of time.

In any typical community, the lower noise levels will be present for a major portion of the time and will consist of natural sounds such as leaves rustling, flowing water, bird or animal noises. These noises are often accompanied, or perhaps dominated, by distant traffic noise or steady industrial noise. The next higher noise levels will be present for a shorter duration and be generated by such sources as nearby highways and industry. Increasing again in level, and decreasing in duration, local traffic would contribute next to the sound pattern. Trucks and trains would have higher levels but are present only for short periods of time. Sources generating even higher levels are children shouting, dogs barking and even thunder, all of which are fortunately only present for very short periods of time. It is, of course, difficult to generalize the sound level variation with time in a community, but it can be judged from the example given that, as the sound level increases, then it is present for shorter periods of time. This trade-off relationship between level and time duration is generally typical of most community noise situations.

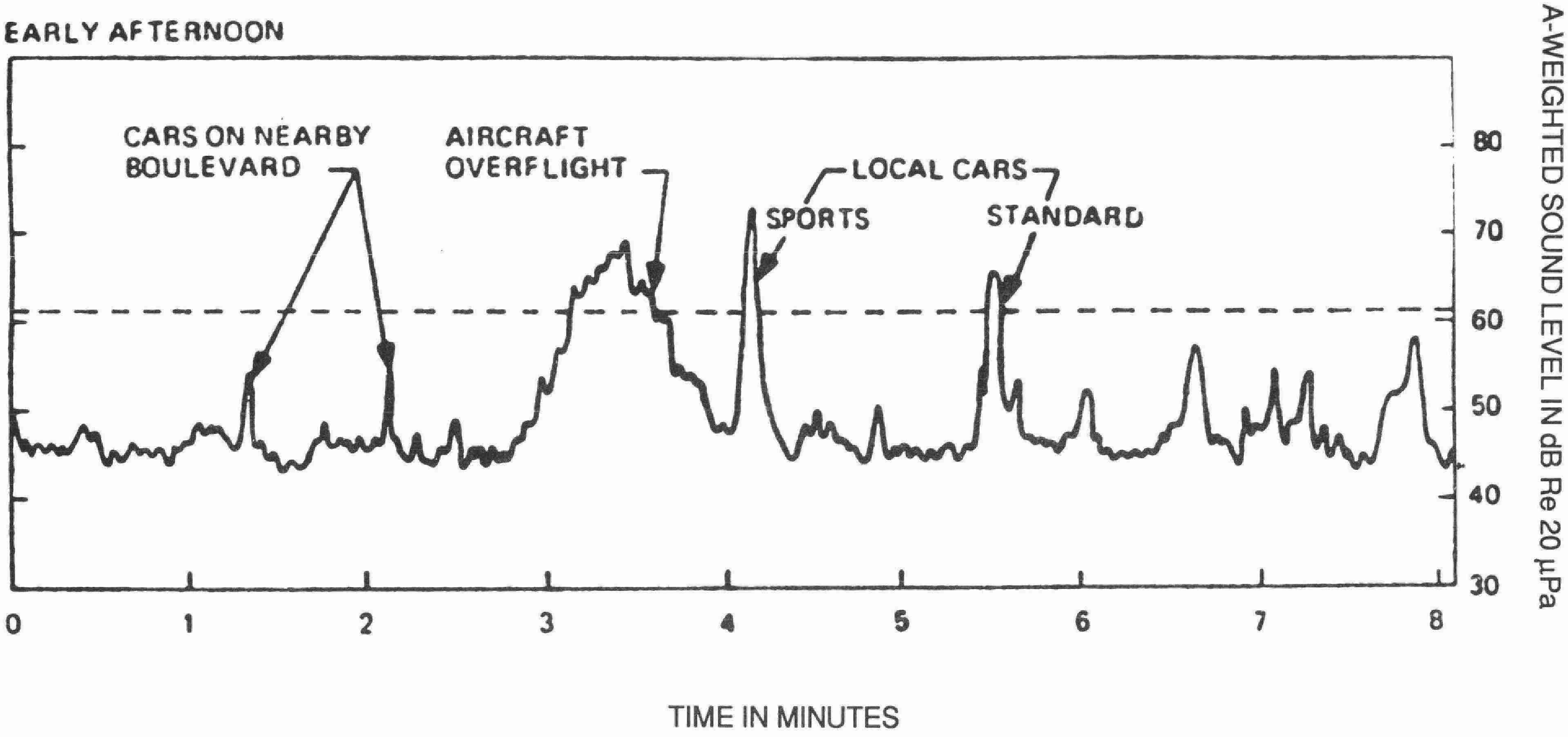


Figure 5.1. Representative graphic time history of sound level as sampled in an urban area. Dashed line represents equivalent energy concept.

2.1 Range of Variation in Community Noise Levels

To give some idea of the possible variation of community noise levels with time consider the two extreme situations; in the first case the community is located adjacent to a busy freeway and at all times the noise climate is dominated by the free flowing traffic. Typical variation in the community noise level is 10 to 20 dB.

At the other extreme, consider the situation of a small community situated close to railway tracks. At night with no train passbys the noise level in the community may be very low, typically 25 to 30 dBA in quiet surroundings. However, as a train passes by the noise levels could increase up to 90 dBA. This gives a sound level range of some 60 dBA. Specialized instrumentation may be required if acoustic measurements are to be conducted.

2.2 The Limitations of the Sound Level Meter for Community Noise Measurement

It was pointed out earlier that community noise levels vary from 10 to 60 dB between quiet and noisy periods, depending on the type of noise source. A simple sound level meter is usually not sufficient to measure such unsteady noises. If a sound level meter needle shows a range of deflections greater than 3 dB, then a single, eyeball-average sound level will not accurately reflect the noise environment. Many community noise situations will produce deflection ranges greater than 3 dB, making the simple sound level meter unsuitable for community noise measurement.

A further problem may occur because most early sound level meters can only measure sound levels that have a range of 10 to 15 dB. Even though a sound level meter may be

suitable for community noise analysis its limited scale range does restrict the use of the instrument.

2.3 Using a Sound Level Meter to Obtain a Series of Community Noise Measurements

The simple sound level meter can be used for the assessment of non-steady community noise by taking single sound level measurements at certain regular intervals (say 10, 20 or 30 seconds) over a specified measurement duration. Assume that a sound level meter was used close to a busy highway, where the variation is only 10 to 20 dB. Noise level readings were taken at exactly 10 second intervals for 10 minutes, resulting in 60 single sound level measurements. The results were rounded off to the nearest A-weighted decibel and entered into the following chart in Figure 5.2, each box representing one sound level reading.

The chart provides a useful picture of the whole variation of the noise level over the ten minute period. The noise level never fell below 65 dBA. The noise level was steady for a long time at 70 dBA, this level probably being associated with individual car passbys.

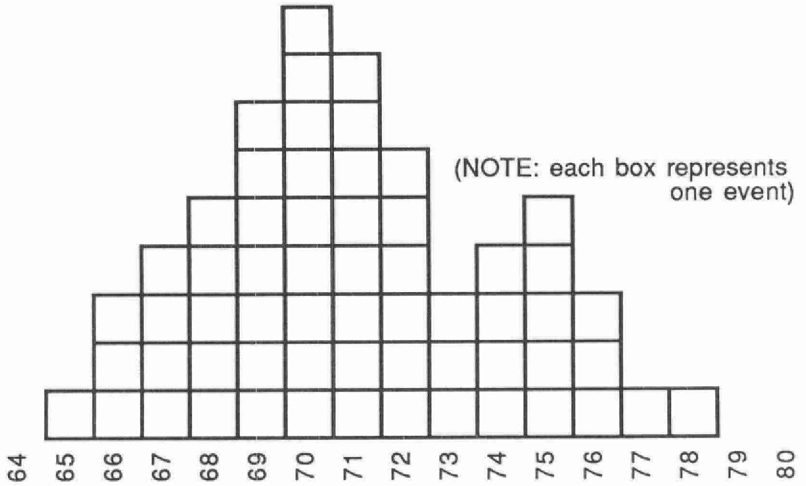


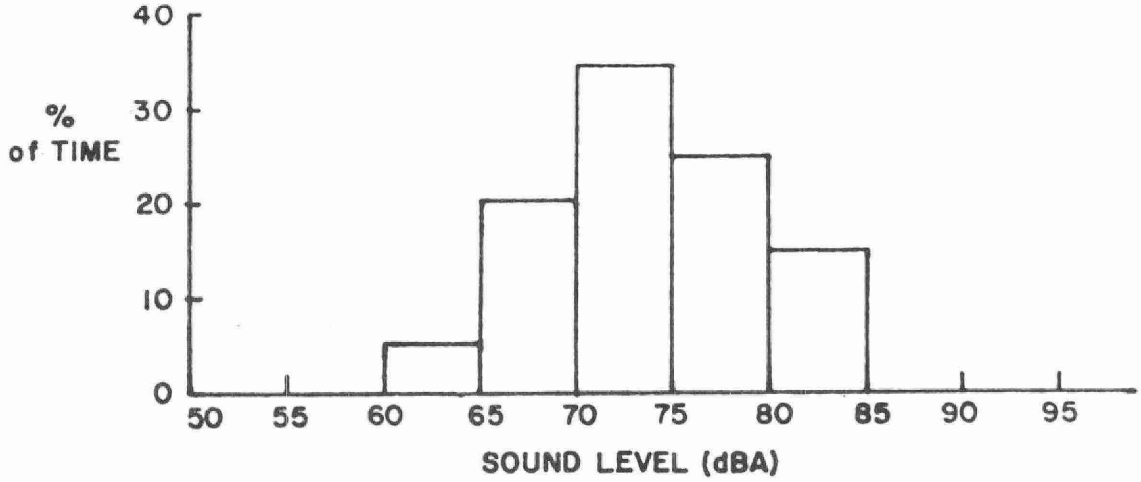
Figure 5.2. Typical histogram of sound level measurements adjacent to a freeway

A second peak occurred at a sound level of 75 dBA which probably represents individual truck passbys, which would be less frequent than the cars, but at a higher noise level. The maximum sound level recorded was 78 dBA. Thus the chart provided a useful picture of the noise variation over the 10 minute period. Such a chart is known as a histogram, and is a diagrammatic representation of the statistical distribution of the sound variation during specified time period.

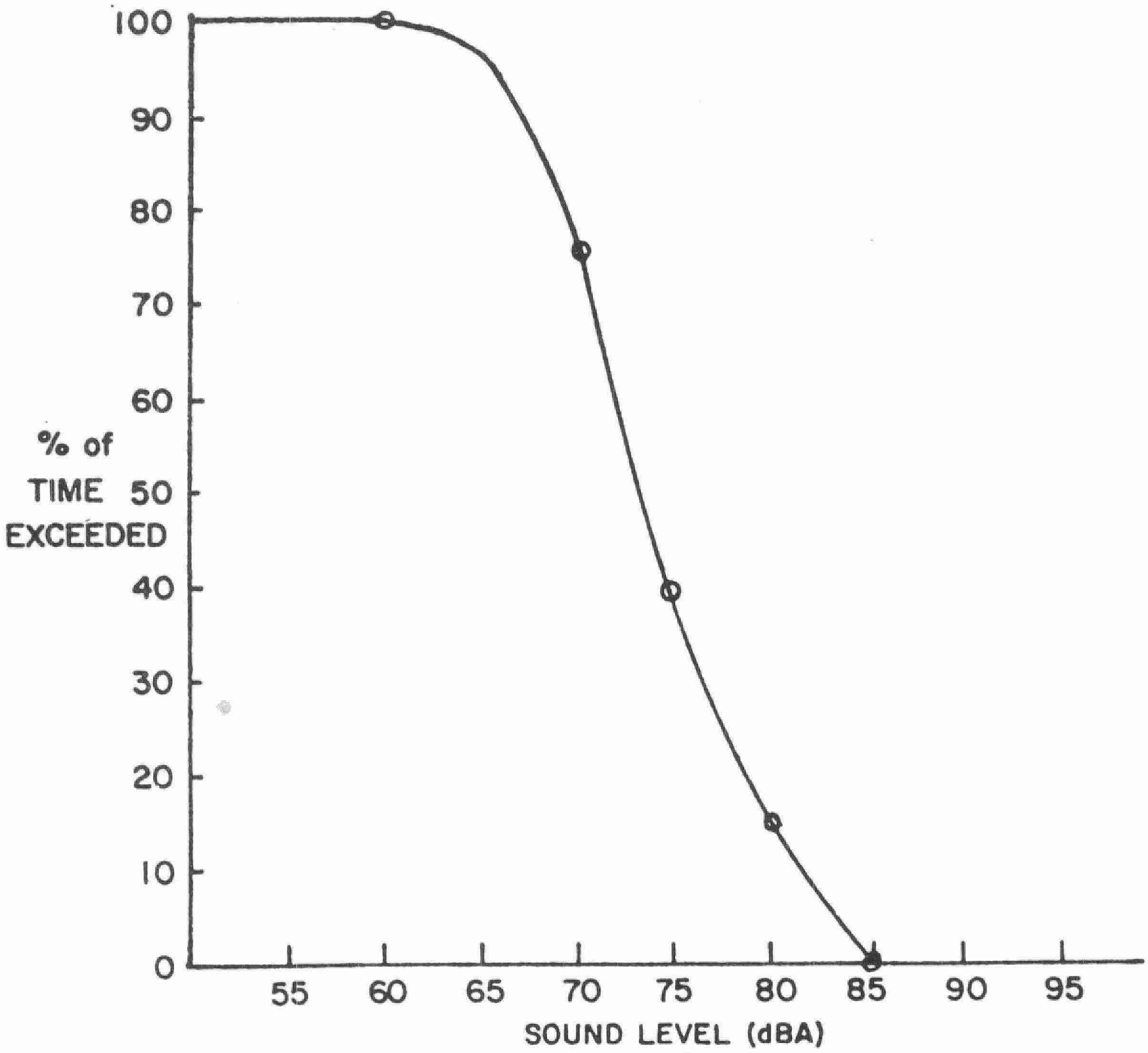
3.0 STATISTICAL SOUND LEVELS

Although time histories such as the one shown in Figure 5.1 are quite illustrative, a more convenient way to describe fluctuating environmental noise is to adopt a purely statistical approach that takes into consideration the total time or proportion of time the sound of interest is present at various specific levels.

The time varying sound level data can be represented in the form of a histogram (a sample is shown in Figure 5.2) or a cumulative distribution curve, each of which denotes levels of noise which are exceeded for given percentages of the time over given periods of observation, or, conversely, the proportion of time certain noise levels are exceeded. The relevant statistic is generally expressed as a noise level, L_N, which is exceeded for N percent of the time. An example of a statistical distribution of time-varying urban noise is concisely illustrated in Figure 5.3.



STATISTICAL DISTRIBUTION



CUMULATIVE DISTRIBUTION

Figure 5.3. Generation of cumulative distribution plot from statistical distribution plot.

4.0 DEFINITIONS AND USE OF L_N, L_{100}, L_{90}, L_{50}, L_{10} and L_0

We have just seen that a cumulative distribution is a plot of the percentage of time for which certain sound levels were exceeded. In order to extract useful information from the plot, very often the reverse question "What level was exceeded for a certain percentage of the time?" is presented. For instance, it may be required to know what level was exceeded for 10% of the time? Looking at the plot on statistical distribution paper, we see that the level exceeded for 10% of the time was 82 dBA. Such levels are often known as L_N values, L_N being defined as follows:

- L_N is the level exceeded for N% of the time. Common L_N values used are as follows:

- L_{100}: the level exceeded for 100% of the time or the lowest noise level.

- L_{90}: the level exceeded for 90% of the time or an indicator of the "ambient" noise level.

- L_{50}: the level exceeded for 50% of the time or the "medium" noise level.

- L_{10}: the level exceeded for 10% of the time, measures the "average level of intrusive" noises.

- L_0: the level exceeded for 0% of the time or the "highest" noise level (also known as L_{MAX}).

By convention L_{90}, L_{50}, and L_{10} are used in common practice to represent approximate measures of background,

median and intensive noise levels respectively. These statistical values form the basis of many environmental noise rating methods.

4.1 Derivations of Percentile Levels from Cumulative Distribution Graph

The percentile levels can be obtained from the cumulative distribution plot. Specific values of six most common descriptors taken from the graph in Figure 5.3 are:

L_N	**Sound Level** dBA
L_{100}	60
L_{90}	67
L_{50}	74
L_{10}	81
L_1	84
L_0	85

5.0 CONCEPT OF THE EQUIVALENT ENERGY CONTINUOUS LEVELS

For many years acousticians have searched for a method of describing time varying sounds by a single number rather than by the entire cumulative distribution or certain L_N values obtained from such a distribution.

In order to assess time-varying noises, the unsteady sound level (still measured in dBA) could be averaged in some way to provide a steady level which would be "equivalent" to the original varying sound. Considerable research has been done to determine how this averaging should be performed.

Simple averaging of the time-varying pressure of the sound is not a good method of assessing the annoyance of unsteady, intrusive value. This method tends to underestimate the annoyance value. It has been found that if the energy (which is proportional to the square of the pressure) of a time-varying sound is averaged, then the resulting equivalent energy continuous levelm, Leq, has good correlation with the annoyance of that sound.

For the purpose of certain environmental noise controls, the community noise descriptor, Leq, has been selected. The adoption of Leq does not necessarily preclude the use of other descriptors.

5.1 The Definition of Leq

The equivalent energy level is that constant sound level which has the same energy as a time-varying noise level for a specified time duration. In order to understand fully the concept of Leq it is also necessary to consider the mathematical definition.

$$Leq = 10 \log (1/T) \int_{o}^{T} [P_A{}^2(t)/P_o{}^2]\, dt, \quad dBA$$

Where P_o = the standard reference pressure
$P_A(t)$ = the A-weighted time varying pressure
T = the measured duration (5.1)

Example:

The noise from a certain machine was measured for a one hour period. The sound levels and the respective time durations were as follows:

78 dBA for 30 minutes
81 dBA for 20 minutes
83 dBA for 10 minutes

(NOTE: the total time of measurement is 60 minutes.) Calculate the Leq value for one hour.

First the sound level relationship must be applied to find the pressure squared ratio for each time period.

$$L_A = 10 \log [P_A/P_o]^2$$

$$[P_A/P_o]^2 = \text{antilog } [L_A/10]$$

Thus to determine the pressure squared ratio, each sound level must be divided by ten and antilog is obtained as follows:

78 ÷ 10 gives 7.8, antilog of 7.8 is 6.3×10^7 for 30 minutes.

81 ÷ 10 is 8.1, antilog of 8.1 is 1.25×10^8 for 20 minutes.

83 ÷ 10 is 8.3, antilog of 8.3 is 2.0×10^8 for 10 minutes.

Now, the equation (5.1) can be used to integrate these levels over a 60 minute period.

$$\begin{aligned}
Leq &= 10 \log (1/60)[6.3 \times 10^7 \times 30 + 1.25 \times 10^8 \times 20 + 2.0 \times 10^8 \times 10] \\
&= 10 \log (1/60)[189 \times 10^7 + 25 \times 10^8 + 20 \times 10^8] \\
&= 10 \log [63.9 \times 10^8]/60 \\
&= 10 \log [1.06 \times 10^8] \\
&= 10 \times 8.03 \\
&= 80.3
\end{aligned}$$

Leq = 80 dBA for one hour

It is interesting to consider the Leq derivation for constant sound level. In this case the averaging process (integration over time T and division by time T) is unnecessary as the average of a constant is that constant. Thus for a constant sound level the equation reduces to exactly the same equation as the definition of dBA, that is for a steady sound:

$$Leq = L_A = 10 \log [P_A/P_o]^2 \qquad (5.2)$$

Thus for a steady sound the Leq value will be the same as the SPL value.

6.0 TRADE-OFF RELATIONSHIP OF TIME VERSUS SOUND LEVEL

Leq measurement is always performed for a particular time duration. It is necessary to state the time period for the measurement along with the Leq. If there are two noise sources which are "on" for different time durations, two sources cannot be directly compared by their respective Leq values. One of the Leq values must first be corrected to the same time duration as the other source to allow direct comparison of levels. To be able to do this a trade-off relationship between sound level and time is used.

The trade-off relationship can easily be derived from the mathematical definition of Leq given in equation 5.1. Let a noise source produce a certain Leq_1 with a corresponding pressure Peq_1 for a time T_1. Consider the effect of taking an Leq measurement over a longer time T_2. Let the value of Leq obtained from this longer test be Leq_2 then:

$$\mathrm{Leq}_2 = 10 \log\,[1/T_2] \int_0^{T_1} [\mathrm{Peq}_1/P_O]^2\,dt, \quad \mathrm{dBA} \qquad (5.3)$$

The pressure Peq_1 need only be integrated over time T_1 as it is "off" for the rest of the time under consideration.

$$\begin{aligned}\mathrm{Leq}_2 &= 10 \log\,[T_1/T_2]\,[\mathrm{Peq}_1/P_O]^2 \\ &= 10 \log\,[T_1/T_2] + 10 \log\,[\mathrm{Peq}_1/P_O]^2 \\ &= 10 \log\,[T_1/T_2] + \mathrm{Leq}_1 \\ &= \mathrm{Leq}_1 - 10 \log\,[T_2/T_1],\ \mathrm{dBA} \qquad (5.4)\end{aligned}$$

This relation shows that an Leq value for a certain time duration will always be decreased when the time is lengthened.

The trade-off relation must always be used with care. Before it is used, it is necessary to understand the correct method of extending the result of an Leq measurement to a longer duration. Two situations exist. First, if a short representative sample is taken of a noise source, the Leq value obtained will apply for as long as the source is "on". For times longer than for which the machine is "on", that is time which includes periods when the machine is "off", then the trading relationship must be used. The time during which the source is "off" will reduce the resultant Leq.

6.1 Example of Transforming Measured Leq Values to a Different Time Duration

This transformation can be illustrated through the following example:

Example:

A representative sample of noise was taken for 5 minutes, and the Leq value of 69 dBA calculated. By observation it was found that the source in question was "on" for a total of six hours between 07:00 and 19:00. Calculate the Leq for the day time period (07:00 to 19:00 hours).

Leq for 5 minutes = 69 dBA
Leq for 6 hours = 69 dBA
(machine is "on" for 6 hours)

The Leq for 12 hours (07:00 to 19:00) is required ∴ T_1 = 6 hours, T_2 = 12 hours.

Leq = 69 - 10 log (12/6) [refer to equation (5.4)]
= 69 - 10 x log 2
= 69 - 10 x 0.3
= 69 - 3
= 66 dBA for 12 hours

- It should be noted that if the duration is doubled then 3 dBA is subtracted from the measured Leq to give the measured Leq value for the longer time duration.

- Also note that Leq values for 5 minutes and 6 hours are the same since the 5 minute sample was a representative sample of the noise.

7.0 THE TIME DURATION IN COMMUNITY NOISE ANALYSIS

When taking community noise measurements, it is very important to obtain a representative sample. Consider the situation of an industry producing fairly continuous mid-level noise and occasionally performing a venting operation which produces a higher level for a short period of time. In this case, a time period must be used which contains both noise situations, and further, does not place unequal weight on either situation. To ensure that a representative sample has, in fact, been taken, a considerable time period may have to be analysed. In some cases up to several hours or the entire day, evening or night period are monitored on the site and the results analysed.

7.1 Ministry of the Environment Guidelines

The Ministry uses two sets of procedures to analyze community noise which are outlined below.

7.1.1 For most land use applications the time duration is divided into day/night periods. The daytime is 16 hours in duration from 07:00 hours to 23:00 hours. The nighttime is the eight-hour period from 23:00 hours to 07:00 hours. The Leq is required for the 16-hour and eight-hour periods. The details of the procedures will be described in subsequent chapters.

7.1.2 For land use application where the noise source is aircraft flyover noise, the Ministry procedures use noise contours determined using the entire 24-hour period.

For the three different time periods described above, the sound level evaluation either by prediction or by measurements can be limited to a representative one-hour time period if the output from the noise source does not vary considerably. Examples of such sources are road traffic, an industry with repetitive processes, etc.

In summary, one hour Leq analysis will be adequate in most instances as the representative value in each of the three different time periods used by the Ministry.

CHAPTER 6

SOUND LEVEL LIMITS

1.0 THE NEED FOR SOUND LEVEL LIMITS

High noise levels can have adverse effects on human beings through speech, activity, comfort, sleep interference, etc. It is essential then to establish sound level limits. A set of sound level limits are required for two basic reasons: first to decide whether a particular noise environment is excessive and, second, as an objective for the design of noise control measures when sound levels are found to be excessive.

The stages in setting up sound level limits follow fairly naturally from these two requirements. First, the various human activities in their appropriate locales (residence, motel, office, etc.) must be listed; second, the time and place of such activities should be determined; third, the noise level descriptors (such as Leq, L_1, L_{10}, etc.) most applicable to the particular activity interference should be determined; and, finally, a number assigned to the descriptor(s) to act as the dividing line between acceptable and unacceptable noise noise environments and also as a target for noise abatement.

A summary of human activities on residential property is given in Table 6.1.

Activity	Time	Place
Gardening	day and evening	outdoors
Relaxing (listening to music, watching T.V., etc.)	day and evening	outdoors and indoors, livingroom
Studying	weekends, evening weekdays	indoors, livingroom
Cooking	prior to any mealtime day and evening	indoors, kitchen
Sleeping	night (and day)	indoors, bedroom
Conversation (including telephone)	day and evening	indoors and outdoors

Table 6.1. Summary of activities on residential property

In addition to these activities, certain other factors need consideration. Annoyance is one example of this. Even though a person is doing nothing in particular, a noise could well be annoying, irritating or unbearable, in spite of the fact the noise did not disturb any particular activity. Hearing loss may also be a consideration. There is some support for the theory that even common everyday sound sources such as vacuum cleaners, radios or local traffic can contribute to hearing loss. What was thought to be an age-induced hearing loss could well be a loss due to continuous exposure to moderate sound levels.

The choice of noise descriptors for rating particular noises is an area of continuing discussion in the acoustical community. Many such descriptors exist and the choice of which is the best for all noise sources is not settled. Sociological surveys, jury testing and other research methods have, however, provided valuable information on the relative merits of certain noise descriptors, making possible the selection of a few descriptors to cover most situations. One significant exception to this is aircraft noise, where an individual descriptor and rating system has been set up. Sound level limits for aircraft noise are covered in Chapter 14.

The leading descriptor used by the Ministry of the Environment in its sound level limits is the equivalent energy continuous level (Leq), called equivalent sound level for short.

2.0 SOUND LEVEL LIMITS

The Ministry of the Environment has adopted a set of sound level limits depending on type of noise source which are contained in a series of technical publications attached to the Model Municipal Noise Control By-Law published by the Ministry of the Environment. The sound level limits for community noise is presented in the publication NPC-131, "Guidelines for Noise Control in Land Use Planning" contained in the Model Municipal Noise Control By-Law.

2.1 Indoor Sound Level Limits

The equivalent energy continuous sound level (Leq) limits and the applicable time periods for the indicated types of indoor space are given in Table 6.2. The adjustments

to the limits, if necessary, are given in the next paragraph. These are the minimum requirements and apply in all cases.

When the predominant sound has a pronounced tonal quality such as a whine screech, hiss, or hum or contains pronounced narrow bands of sound energy, as measured by an instrument, then 5 dBA should be deducted from the sound level limits indicated in Table 6.2.

2.2 Outdoor Sound Level Limits

2.2.1 Table 6.3 gives the sound level limits for the equivalent sound level (Leq) for outdoor living areas, where the Leq is referenced to the entire 16 hour period from 07:00 to 23:00 hours.

2.2.2 Table 6.4 gives sound level limits for the equivalent sound level (Leq) for outdoor areas in the vicinity of buildings containing sleeping quarters, where the Leq is referenced to the entire 8 hour period from 23:00 to 7:00 hours.

Compliance with the above outdoor sound level limits should generally ensure compliance with the appropriate requirements of Table 6.2 for the same time period for any normal building construction with open windows. Where requirements of Table 6.4 cannot be met, special architectural design or construction features will have to be incorporated into the building construction to ensure compliance with the appropriate requirements of Table 6.2 for the same time period.

Type of space	Equivalent sound level (L_{eq}) dBA
Bedrooms, sleeping quarters, hospitals, etc. (time period 23:00-07:00 hours)	40
Livingrooms, hotels, motels, etc. (time period 07:00-23:00 hours)	45
Individual or semi-private offices, small conference rooms, reading rooms, classrooms, etc. (time period 07:00-23:00 hours)	45
General offices, reception areas, retail shops and stores, etc. (time period 07:00-23:00 hours)	50

Table 6.2. Indoor sound level limits

Sound descriptor for the entire period	Sound level limit dBA
L_{eq}	55

Table 6.3. Sound level limits for outdoor living areas (07:00-23:00 hours)(a minimum area of 56 m^2)

Sound descriptor for the entire period	Sound level limit dBA
L_{eq}	50

Table 6.4. Sound level limits for outside bedroom windows (23:00-07:00 hours)

3.0 APPLYING SOUND LEVEL GUIDELINES TO RESIDENTIAL LAND USE DEVELOPMENTS

Table 6.5 allows for the determination of the subjective or apparent loudness of the traffic noise on the site, the extent of the noise problem and the necessity for noise control measures. The table should be used in conjunction with the sound level limits discussed in Section 6.2

Excess above recommended sound level limits (dBA)	Change in subjective loudness above	Magnitude of the noise problem	Noise control measures (or action to be taken)
No excess	---	No expected noise problem	None
1 to 5 inclusive	Noticeably louder	Slight noise problem	If no physical measures are taken, then prospective purchasers or tenants should be made aware by suitable warning clauses.
6 to 10 inclusive	Almost twice as loud	Definite noise problem	Recommended
11 to 15 inclusive	Almost three times as loud	Serious noise problem	Strongly recommended
16 and over	Almost four times as loud	Very serious noise problem	Stronly recommended (may be mandatory)

Note: When the excess is more than 5 dBA, the recommended control measures must reduce the sound level to the sound level limit and not with a 5 dBA tolerance (for example outdoor level during daytime, must be reduced to 55 dBA and not 60 dBA).

Table 6.5. Applying recommended sound level limits to residential land use developments

CHAPTER 7

TRANSPORTATION NOISE PREDICTION

1.0 INTRODUCTION

In the field of acoustics and land use planning, prediction methods are used primarily to determine the noise impact from various transportation noise sources such as roads, railways and aircraft operations.

There is a number of reasons for the extensive use of prediction methods in noise impact assessment. First, it allows persons who do not have measurement capabilities to obtain an indication of the noise levels on a particular site. Second, it allows the noise levels on a site to be determined when the constraints of time, money, distance, weather and instrumentation do not permit on-site measurements. The use of prediction methods also allow the evaluation of changes in the transportation facility noise source. For example, the effect of a future increase in the volume of traffic on a particular road can easily be calculated. The prediction methods also allow the effectiveness of some noise control measures to be evaluated particularly the effect of increasing the distance between the noise source and the receiver.

This section will describe the two prediction methods used extensively by this Ministry to determine the noise impact from road traffic and train operations on land being developed for residential use, as well as the guidelines for airport noise assessment.

2.0 GUIDELINES FOR ROAD TRAFFIC NOISE ASSESSMENT

In July 1986 the Ministry of the Environment published a guideline manual for the prediction of road traffic noise. The manual presents a procedure required by this Ministry for the prediction of equivalent energy sound levels, Leq, due to road traffic and the procedure supercedes all other previously used prediction methods. A copy of the publication is enclosed as Appendix A.

2.1 Basic Elements of the Prediction Model

The energy equivalent sound level produced by each class of vehicle is given by:

$Leq(h)_i = [L_o]_{E_i}$ reference energy mean emission level

$+ 10 \log [(N_i \pi D_o)/(S_i T)]$ traffic flow adjustment

$+ 10 \log [D_o/D]^{1+\alpha}$ distance adjustment

$+ 10 \log [\psi_\alpha(\phi_1, \phi_2)/\pi]$ finite roadway adjustment

$+ \Delta s$ shielding adjustment (7.1)

where $Leq(h)_i$	is the hourly equivalent sound level of the ith class of vehicles.
$(L_o)E_i$	is the reference energy emission level of the ith class of vehicles.
N_i	is the number of vehicles in the ith class passing a specified point during some specified time period.

D	is the perpendicular distance, in metres, from the centerline of the traffic lane to the observer.
D_o	is the reference distance at which the emission levels are measured. In the model D_o is 15 m, D_o is a special case of D.
S_i	is the average speed of the ith class of vehicles and is measured in kilometres per hour (km/h).
T	is the time period over which the equivalent sound level is computed.
α	is a site parameter whose values depend upon site conditions.
ψ_α	is a symbol representing a function used for segment adjustments, i.e. an adjustment for finite length roadways.
Δ_s	is the attenuation, in dB, provided by some type of shielding such as barriers, rows of houses, densely wooded areas, etc.

2.1.1 Reference Hourly Sound Level

The reference hourly sound level for all three classes of vehicles is defined as:

$$\begin{aligned} Leq_R(h) = {} & 10 \log [\Sigma(\text{antilog } [L_{OEi}/10]) * P_i] \\ & + 10 \log [ND_o/S] - 25 \end{aligned} \qquad (7.2)$$

where P_i = Percentage of ith class of vehicle (expressed as a fraction of the total volume)

S = posted speed limit in km/h
i = 1, 2 and 3

The reference energy mean emission levels measured at the reference distance of 15 m for automobiles, medium trucks and heavy trucks are given below and also plotted in Figure 7.1:

$$(L_o)_{E_A} = 38.1 \log (S) - 2.4$$

$$(L_o)_{E_{MT}} = 33.9 \log (S) + 16.4$$

$$(L_o)_{E_{HT}} = 24.6 \log (S) + 38.5 \qquad (7.3)$$

For a specific reference distance of 15 m and a reference traffic volume of 40 vehicles per hour, the reference hourly sound level can be expressed as:

$$Leq_R(h) = 10 \log [\Sigma(\text{antilog } [L_{OEi}/10]) * P_i] - 10 \log S + 2.78 \qquad (7.4)$$

i = 1, 2 and 3

The above expression defines the reference hourly sound level presented in Appendix A, Tables 3 to 6.

For heavy trucks travelling in the upgrade direction, the adjustment shall be made by multiplying the percentage of heavy trucks by an adjustment factor given in Table 1 of Appendix A, before applying the above formula or using Tables 3 to 6.

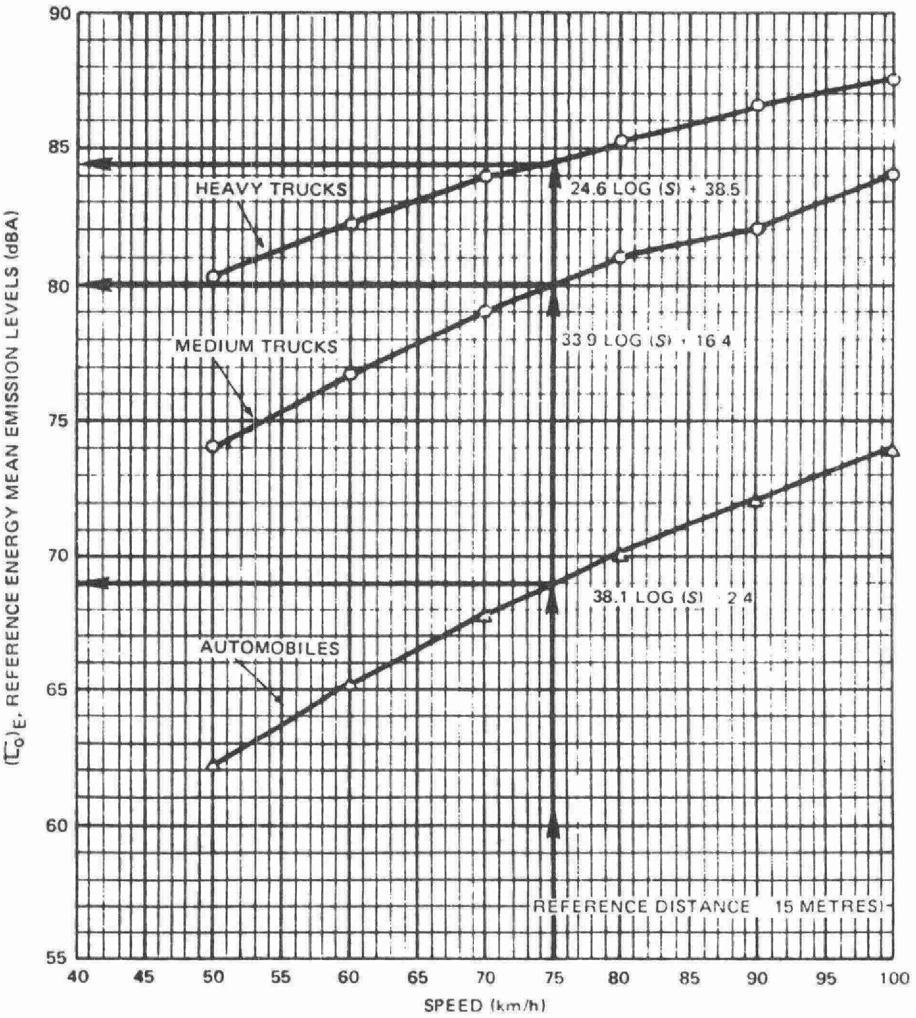


Figure 7.1. Reference energy mean emission levels as a function of speed

2.1.2 Adjustments to Reference Level

(a) Traffic Volume

For volumes other than the reference volume of 40 vehicles per hour, an adjustment must be added. The traffic volume adjustment is given by:

$$\Delta_{vol} = 10 \log (V/40) \qquad (7.5)$$

where V is the total traffic volume

(b) Distance Adjustment

For distances other than the reference distance of 15 m from the centre line of the road, an adjustment must be added. The distance adjustment is given by:

$$\Delta_{dist} = (1 + \alpha) * 10 \log [D_0/D] \qquad (7.6)$$

where D_0 is the reference distance of 15 m from road centreline,

D is the perpendicular distance from the centreline of the road to the point of reception,

and α is the ground absorption co-efficient defined by:

$$\begin{aligned} \alpha &= 0.5 && h \leq 3m \\ &= 0.715\ (1-h/10) && 3m< h <10m \\ &= 0.0 && h \geq 10m \end{aligned}$$

where h is the total effective height. For reflective surface α is equal to zero. The total effective height is computed by adding together the height of the point of reception above the ground, the effective shielding height between the source and the receptor and the effective source height of the road traffic.

The effective source height in metres is given by:

$$s = p^{0.25} \tag{7.7}$$

where p is the unadjusted percentage of heavy trucks.

It should be noted that a lower limit of 0.5 m and an upper limit of 2.4 m apply to the source height.

(c) Road Element Size

When the ground is non-reflective or when the calculation considers a finite section of the road, an adjustment must be added. The value of the adjustment is given by:

$$\begin{aligned}\Delta_{\text{road size}} &= 10 \log \left[(1/\pi) \int_{\Phi_1}^{\Phi_2} (\cos \Phi)^{\frac{1}{2}} \, d\Phi\right] \\ &\quad \text{for non-reflective surfaces} \\ &= 10 \log \left[[\Phi_2 - \Phi_1]/\pi\right] \\ &\quad \text{for reflective surfaces} \qquad (7.8)\end{aligned}$$

where Φ_1 and Φ_2 are the angles subtended by the road section at the point of reception, see Table 10 of Appendix A.

(d) Pavement Surface

An adjustment Δ_{ps} must be added to account for pavement surface type. This adjustment is described in Section 2.2(g)(iv) of Appendix A.

(e) Adjustment for Shielding by Dense Woods and Rows of Houses

An adjustment must be added to account for shielding of dense woods or rows of houses. This adjustment is described in Section 2.2(g)(v) of Appendix A.

(f) Barrier Adjustment

The barrier adjustment accounts for barrier attenuation.

The barrier adjustment is discussed in detail in Chapter 9 and in Appendix A.

2.2 Road Traffic Variables

The following variables are included in the prediction model:

(a) Volumes of cars, medium trucks and heavy trucks/hour
(b) Traffic flow speed
(c) Road gradient
(d) Distance from the centreline of road to the receiver
(e) Total effective height
(f) Road element size
(g) Pavement surface type
(h) Shielding

2.3 Worked Example

Given - automobiles	910 vph
- medium trucks	20 vph
- heavy trucks	70 vph
- posted speed	80 km/h
- distance from centreline	30 m

- road gradient	0%
- road surface type	normal
- topography	flat

2.3.1 Mean Emission Levels at 15 m

Automobile
$$\begin{aligned} [L_o]_{E_A} &= 38.1 \log (S) - 2.4 \\ &= 38.1 \log (80) - 2.4 \\ &= 72.51 - 2.4 \\ &= 70.11 \text{ dBA} \end{aligned}$$

Medium trucks
$$\begin{aligned} [L_o]_{E_{MT}} &= 33.9 \log (S) + 16.4 \\ &= 33.9 \log (80) + 16.4 \\ &= 64.51 + 16.4 \\ &= 80.91 \text{ dBA} \end{aligned}$$

Heavy trucks
$$\begin{aligned} [L_o]_{E_{HT}} &= 24.6 \log (80) + 38.5 \\ &= 46.8 + 38.5 \\ &= 85.32 \text{ dBA} \end{aligned}$$

2.3.2 Reference Hourly Sound Level at 15 m

Using equation (7.2)

$$\begin{aligned} Leq_R(h) &= 10 \log [10^{7.011} * 0.91 + 10^{8.091} * \\ &\quad 0.02 + 10^{8.532} * 0.07] + \\ &\quad 10 \log [1000 * 15/80] - 25 \\ &= 75.52 + 22.73 - 25 \\ &= 73.25 \text{ dBA} \end{aligned}$$

2.3.3 Distance Adjustment

$$\begin{aligned} \text{Source height, } s &= (p)^{0.25} \\ &= (7)^{0.25} \\ &= 1.63 \text{ m} \end{aligned}$$

Total effective height, $h = s + t + p + r$ (see Appendix A)

$$= 1.63 + 0 + 0 + 1.5$$
$$= 3.13 \text{ m}$$

$$\alpha = 0.715\ (1 - h/10)$$
$$= 0.715\ (1 - 3.13/10)$$
$$= 0.49$$

$$\Delta_{dist} = 10 \log (D_o/D)^{1+\alpha}$$
$$= 10 \log (15/30)^{1+0.49}$$
$$= -4.5 \text{ dB}$$

2.3.4 Road Element Size

$$\Delta_{road\ size} = 10 \log [[1/\pi] \int_{\Phi_1}^{\Phi_2} (\cos \Phi)^{\frac{1}{2}} d\Phi]$$

$$= 10 \log [[1/\pi] \int_{-90}^{90} (\cos \Phi)^{\frac{1}{2}} d\Phi]$$

The indicated integration has been performed numerically using the Simpson's Rule:

$$\Delta_{road\ size} = -1.2 \text{ dB}$$

2.3.5 Road Leq(h)

$$\text{Leq}(h) = \text{Leq}_R(h) + \Delta_{dist} + \Delta_{road\ size}$$
$$= 73.25 + (-4.5) + (-1.2)$$
$$= 67.55$$
$$= 68 \text{ dBA}$$

Therefore, the Leq due to the road at a distance of 30 m is 68 dBA.

2.4 Effect of Changing the Traffic Flow Conditions on the Predicted Noise Levels

2.4.1 Effect of Increasing the Traffic Volume

Table 2 of Appendix A or the term 10 log (V/40) indicate the relationship between traffic volume and sound level.

A doubling of the traffic volume (and keeping the other variables constant) results in a 3 dB increase in the sound level.

2.4.2 Effect of Changing the Traffic Flow Speed

Changing the traffic flow speed have a slightly different effect on the sound levels for each classification of vehicles and is dependent on the overall composition of the three classes of vehicles.

In general, the increase in sound levels is about 1-2 dB for every 10 km/h increase in speed and the maximum increase is 3 dB.

2.4.3 Effect of Increasing the Distance

The term in the model which deals with distance attenuation is $10 \log (D_O/D)^{1+\alpha}$.

Reflective Surface

For ground absorption co-efficient, α, equal to zero, the attenuation rate is 3 dB per doubling of distance.

Non-Reflective Surface

For ground absorption co-efficient, α, equal to 0.5 (total effective height ≤ 3 m), the attenuation rate is 4.5 dB per doubling of distance.

For total effective height greater than 3 m and less than or equal to 10 m, α is given by 0.715 (1-h/10). The attenuation rate varies between 4.5 to 3 dB per doubling of distance. And for total effective height greater than 10 m, α is zero. The attenuation rate is 3 dB per doubling of distance.

3.0 GUIDELINES FOR RAIL TRAFFIC NOISE ASSESSMENT

A guideline manual for the prediction of rail traffic noise has been prepared by this Ministry. A copy of the publication is enclosed as Appendix B.

3.1 Basic Elements of the Prediction Model

The noise emitted during passby of a railway train consists of two main components: locomotive engine and exhaust noise; and wheel-rail interaction noise. Whistle noise is not considered part of the general train passby noise.

The mathematical expression governing the above two types of noise are defined in the following sections. Included are also the expressions defining all the various adjustments required to complete the calculation of the equivalent energy sound level, Leq, at a point of reception.

3.1.1 Locomotive Exhaust Noise

The energy equivalent sound level produced by the locomotive engine and exhaust noise at 15 m from the track is given by:

$$Leq,_L = 10 \log N - 10 \log S + 0.15x + 55 + \Delta_{tot}, \quad S<30 \text{ km/h}$$

$$= 10 \log N + 13.5 \log S + 0.15x + 22 + \Delta_{tot}, \quad S>30 \text{ km/h} \qquad (7.9)$$

where N is the total number of locomotives in a 24-hour period,

x is the number of cars per locomotive,

S is the operating speed, km/h,

and Δ_{tot} is the total adjustment for locomotive noise (Section 3.1.3).

3.1.2 Wheel-rail Interaction Noise

The equivalent energy sound level produced by the wheel-rail interaction noise at 15 m from the track is given by:

$$Leq,_W = 5.3 + 10 \log n + 15.7 \log S + \Delta_{tot} \qquad (7.10)$$

where n is the number of railway cars in a 24-hour period

and Δ_{tot} is total adjustment for wheel-rail noise (Section 3.1.3).

S is the operating speed, km/h.

3.1.3 Adjustments

(a) Distance Adjustment

For distances other than the reference distance of 15 m from the centreline of the track, an adjustment must be added. The distance adjustment is given by:

$$\Delta_{dist} = 10 \log (D_0/D)^{1+\alpha}$$

where D_0 is the reference distance of 15 m from track centreline,

D is the perpendicular distance from the centreline of the track to the point of reception,

and α is the ground absorption co-efficient defined by:

$$\begin{aligned} \alpha &= 0.5, & h &\leq 3\text{m} \\ &= 0.715\ (1 - h/10), & 3\text{m} < h &< 10\text{m} \\ &= 0.0 & h &\geq 10\text{m} \end{aligned}$$

where h is the total effective height.

For reflective ground surface $\alpha = 0.0$.

(b) Track Length and Ground Surface Adjustment

When the ground is non-reflective or when the calculation considers a finite section of the track, an adjustment must be added. The value of the adjustment is given by:

$$\Delta_{track} = 10 \log \left[(1/\pi) \int_{\Phi_1}^{\Phi_2} (\cos \Phi)^{\frac{1}{2}}\, d\Phi\right]$$

for non-reflective surfaces

$$= 10 \log [(\Phi_2 - \Phi_1)/\pi]$$

for reflective surfaces

where Φ_1 and Φ_2 are the angles subtended by the track section at the point of reception, see Table 8 of Appendix B.

(d) Adjustment for Shielding By Dense Woods and Rows of Houses

An adjustment Δ_{wh} must be added to account for shielding of dense woods or rows of houses. This adjustment is described in Section 3.4(b) of the Appendix B.

(d) Barrier Adjustment

The barrier adjustment accounts for barrier attenuation.

This adjustment is discussed in detail in Chapter 9 and in Appendix B.

(e) Time Period Adjustment

The sound level calculation must be adjusted for the time period to which the train traffic is applicable. This adjustment is given by:

$$\Delta_{time} = 10 \log (T_{ref}/T)$$

where T_{ref} is a 24-hour period

and T is the relevant time period, such as 8-hour or 16-hour. (7.11)

3.2 Traffic Information Required

The following information, which is required in order to use the train noise prediction method, can usually be obtained from the local stationmaster, trainmaster or dispatcher of the railroad owning the tracks. In addition to obtaining information on the present or existing train operations, it is important to find out if any future increases (or decreases) in the number of trains using the line can be expected. This information is particularly important in areas where a commuter rail service such as GO Transit may be a future possibility. These commuter operations can increase the number of trains on a rail line by a significant amount.

The information required is as follows:

(a) The number of train movements per day on the railway line in question. If possible, this information should be broken into:

  (a) Time of day;

    (i) the number and type of trains during the daytime period (07:00 to 23:00 hours);

    (ii) the number and type of trains during the night time period (23:00 to 07:00 hours).

  (b) Type;

    The type of train refers to whether the train is a passenger, a freight or switcher.

(c) The average number of locomotives (if available) and the average number of cars for each type of train.

(d) The average speed (in km/h) of each type of train.

3.3 Worked Example

Given:

Time Period = 07:00 to 23:00 hours
Train Type = freight
No. of trains = 17
No. of cars per train = 90
No. of locomotives per train = 3
Speed = 80 km/h
Distance = 30 m
Topography = flat and absorptive

3.3.1 Reference Locomotive Sound Level at 15 m

$$\begin{aligned} Leq_{L,}15 &= 10 \log N + 13.5 \log S + 0.15x + 22 \\ &= 10 \log (17 \times 3) + 13.5 \log (80) + 0.15 \times 30 \\ &\quad + 22 \\ &= 17.08 + 25.69 + 4.5 + 22 \\ &= 69.27 \text{ dBA} \end{aligned}$$

3.3.2 Distance Adjustment

$$\begin{aligned} \text{Total effective height, } h, &= s + t + p + r \text{ (see Appendix B)} \\ &= 4 + 0 + 0 + 1.5 \\ &= 5.5 \text{ m} \end{aligned}$$

$$\begin{aligned} \alpha &= 0.715 \, (1 - h/10) \\ &= 0.715 \, (1 - 5.5/10) \\ &= 0.32 \end{aligned}$$

$$\Delta dist = 10 \log (D_0/D)^{1+\alpha}$$
$$= 10 \log (15/30)^{1+0.32}$$
$$= -3.97 \text{ dB}$$

3.3.3 Locomotive Sound Level at Distance = 30 m

$$Leq_{L,d} = Leq_{L,15} + \Delta_{dist}$$
$$= 69.27 + (-3.97)$$
$$= 65.3 \text{ dBA}$$

3.3.4 Reference Wheel-Rail Sound Level at 15 m

$$Leq_{W,15} = 5.3 + 10 \log n + 15.7 \log S$$

$$= 5.3 + 10 \log (1530) + 15.7 \log (80)$$
$$= 5.3 + 31.85 + 29.88$$
$$= 67.03 \text{ dBA}$$

3.3.5 Distance Adjustment

Total effective height, $h = s + t + p + r$
$= 0.5 + 0 + 0 + 1.5$
$= 2$ m

$\alpha = 0.5$

$$\Delta_{dist} = 10 \log (D_o/D)^{1+\alpha}$$

$$= 10 \log (15/30)^{1+0.5}$$
$$= -4.5 \text{ dB}$$

3.3.6 Wheel-Rail Sound Level at Distance = 30 m

$$\begin{aligned} Leq_{W,d} &= Leq_{W,15} + \Delta_{dist} \\ &= 67 - 4.5 \\ &= 62.5 \text{ dBA} \end{aligned}$$

3.3.7 Locomotive and Wheel-Rail Sound Level

$$\begin{aligned} Leq &= Leq_{L,d} + Leq_{W,d} \\ &= 65.3 + 62.5 \\ &= 67.13 \text{ dBA} \end{aligned}$$

3.3.8 Track Length Adjustment

$$\begin{aligned} \Delta_{track} &= 10 \log \left[1/\pi \int_{\Phi_1}^{\Phi_2} (\cos \Phi)^{\frac{1}{2}} \, d\Phi\right] \\ &= 10 \log \left[1/\pi \int_{-90}^{90} (\cos \Phi)^{\frac{1}{2}} \, d\Phi\right] \end{aligned}$$

The indicated integration has been performed numerically using the Simpson's Rule.

$$\Delta_{track} = -1.2 \text{ dB}$$

3.3.9 Time Period Adjustment

$$\begin{aligned} \Delta_{time} &= 10 \log (T_{ref}/T) \\ &= 10 \log (24/16) \\ &= 1.8 \text{ dB} \end{aligned}$$

3.3.10 Overall Leq

$$\begin{aligned} Leq &= Leq + \Delta_{track} + \Delta_{time} \\ &= 67.13 + (-1.2) + 1.8 \\ &= 67.73 \\ &= 68 \text{ dBA} \end{aligned}$$

Therefore, the daytime Leq at a distance of 30 m from the track is 68 dBA.

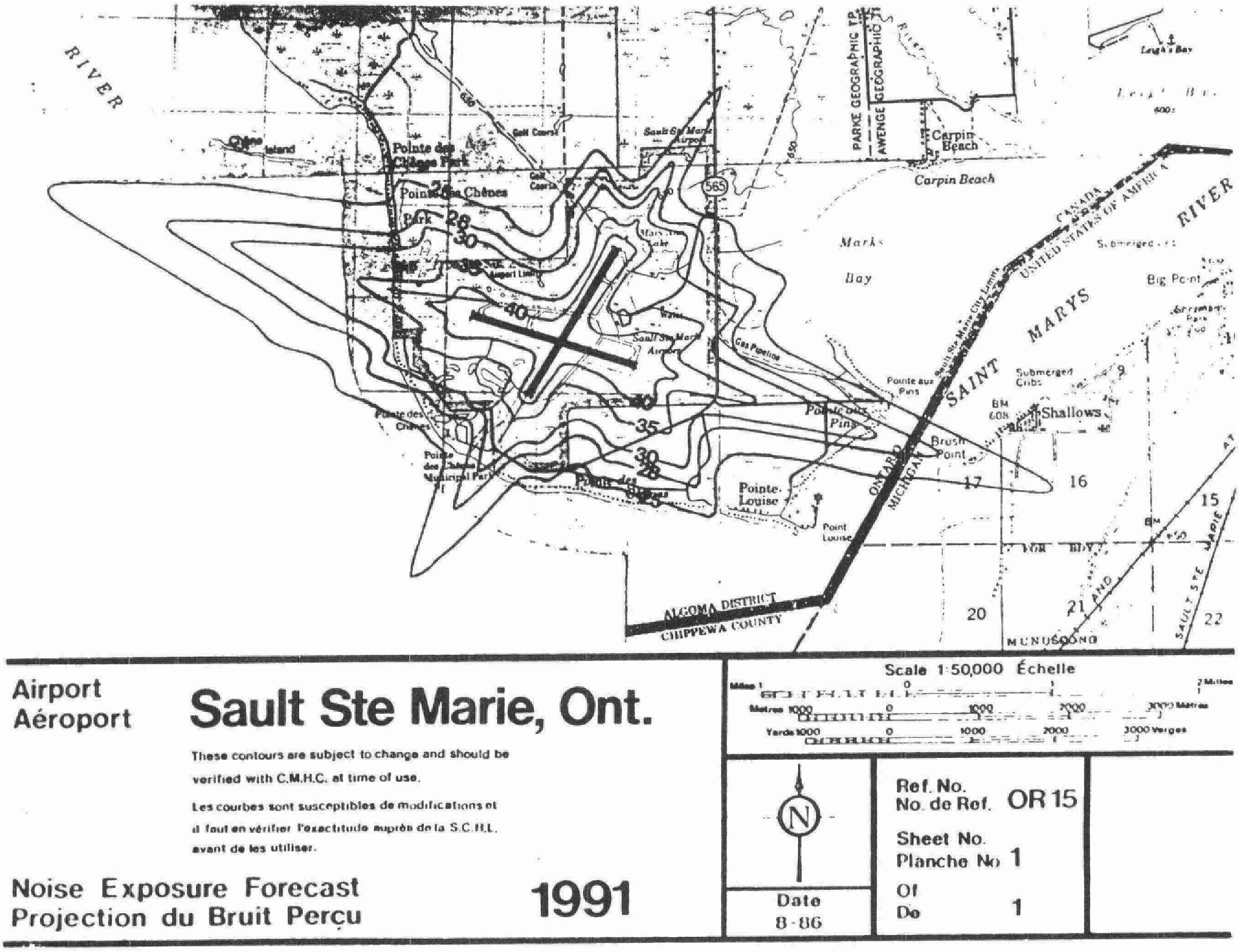
4.0 GUIDELINES FOR AIRPORT NOISE ASSESSMENT

The procedure for airport noise assessment is based on the Noise Exposure Forecast (NEF) and Noise Exposure Projection (NEP) system.

All land use proposals near airports must conform to the NEF Land Use Compatibility Table contained in the Ministry of Housing publication "Land Use Policy Near Airports", March 1978. A copy of the publication is enclosed as Appendix C.

The calculation of NEF requires information about the types of aircraft using the airport and the noise they generate, the number of take-offs and landings on each runway and when the take-offs and landings occur.

A summation is made of the noise from all aircraft types on all runways in calculating NEF values, taking into account the subjectively annoying effects of aircraft noise including pure tones and duration. The system is used primarily to develop noise contours for areas around airports, although it can be used to provide a noise exposure value for one particular location. Figure 7.2 illustrates an NEF contour map for a Canadian airport of



Airport
Aéroport

Sault Ste Marie, Ont.

These contours are subject to change and should be verified with C.M.H.C. at time of use.

Les courbes sont susceptibles de modifications et il faut en vérifier l'exactitude auprès de la S.C.H.L. avant de les utiliser.

Noise Exposure Forecast
Projection du Bruit Perçu

1991

Date
8-86

Ref. No.
No. de Ref. OR 15

Sheet No.
Planche No 1

Of
De 1

Figure 7.2. NEF contour map around a Canadian airport

medium size. It is important to note that NEF values increase in logarithmic manner.

Transport Canada has provided noise exposure forecast contour maps for major airports in Canada. These maps are based upon the most up-to-date information available, and where possible, on expected future conditions. They will be revised as airport conditions change. Figure 7.3 provides a list of the NEF/NEP contour maps currently to be used in Ontario.

The accuracy of the NEF contours will typically be highest near the runways, and will gradually decrease with increasing distance from the runways. NEF contours are typically based on the average operation over a year, although where there are large seasonal variations in operation, NEF contours are developed for representative seasons. In either case, the aircraft operational data (number and types) for a given time period is averaged for the time period under consideration. It must be remembered that actual operations on any given day may exhibit large departures from the averaged operational data. Therefore, judgement or analysis of aircraft noise data for any given day may not be realistic in light of such variations.

Sociological surveys have indicated that adverse community reaction may start about 25 NEF. Above 30 NEF, complaints become increasingly vigorous and may be expected to take the form of concerted group action. Above 40 NEF legal action may be expected.

The following approximate conversion holds for NEF and Leq_{24}:

$$Leq_{24} = NEF + 31, \quad dBA \tag{7.12}$$

A list of the maps currently (December 1986) to be used in applying the 1978 Land Use Policy near airports.

Airport	Date of Latest Revision	Projection Date
	NEF MAPS	
Brantford	August 1977	1991
Buttonville	March 1986	1991
Carp	May 1973	G.A.
Hamilton	July 1981	1988
Kingston	September 1978	1986
London	June 1986	1991
Maple	March 1981	1987
North Bay	December 1980	1985
Ottawa*	December 1983	1988
Pembroke	December 1985	1991
Sarnia	August 1978	1986
Sault Ste. Marie	1986	1991
Sioux Lookout	March 1986	1991
Sudbury	June 1973	1976
Thunder Bay	November 1984	1989
Toronto (Pearson)*	July 1980	1986
Toronto Island	April 1978	1990
C.F.B. Trenton	November 1985	1990
Waterloo-Guelph	April 1977	1985
Wiarton	February 1979	G.A.
Windsor	February 1979	1985
	NEP MAPS	
Oshawa **	December 1982	1991
Ottawa*	November 1984	2000
Toronto (Pearson)*	May 1984	1996
Markham	December 1982	1988

* Both the NEF and the NEP contours apply and land use proposals should not conflict with either.

** NEF contours have also been published for Oshawa but since they lie within the NEP contours, they are not referred to in applying the policy.

Figure 7.3. NEF and NEP contour maps

5.0 REFLECTIONS FROM BUILDING SURFACES

The road and rail traffic noise prediction methods detailed in Sections 2 and 3 apply to a "free-field" sound level at receptor locations where the proposed structures are to be constructed. The prediction methods have made no allowance for reflections from the building facade. Therefore, an adjustment must be added to account for reflections from the building facade. This adjustment is described in Appendix D.

5.1 Level in Outdoor Living Area

The usual practice in land use planning is to estimate the outdoor living area noise level (Leq, dBA) during the daytime hours at 3 m away from the building facade and 1.5 m above ground level. The prediction methods calculate the "free-field" sound level. To account for the reflections from the building facade, 2 dB adjustments should be added to the predicted "free-field" outdoor sound level.

For instance, in the worked example in Section 2.3 for road traffic, the corrected outdoor living area sound level is (68 + 2) = 70 dBA. Similarly for train noise, in Section 3.3, corrected noise level in the outdoor living area is (68 + 2) = 70 dBA.

Note:

1. The above adjustment is also valid for corner lots even when there is an acoustic fence parallel to the noise source, and the fence has a wrap-around the

property line (see Figure 1). Municipally approved fences are not very high and the reflections from the fence are minimal.

2. If the outdoor living area is located on the shielded side (away from the noise source) of the building facade, no extra adjustment is required.

5.2 Level Near Building Facades

The indoor noise control measures are usually determined in land use planning by evaluating the sound level outside the second storey bedroom window. To account for the reflections from the building facade, 3 dB adjustments should be added to the predicted "free-field" sound level.

For sample calculations and detailed descriptions, refer to Chapter 10 and Appendix D.

6.0 COMPUTER PROGRAM (TRAFFIC NOISE)

The Noise Assessment Unit has prepared a computerized version of the Guidelines for Road Traffic Noise Assessment. The program has been written for the IBM personal computers or compatibles. A copy of the program documentation is enclosed as Appendix E.

Copies of the computer program may be obtained from the Noise Assessment Unit, Ministry of the Environment.

CHAPTER 8

NOISE CONTROL MEASURES FOR RESIDENTIAL DEVELOPMENT

1.0 INTRODUCTION

In this chapter "noise control measures" are discussed for lowering indoor and outdoor noise levels to acceptable limits in residential areas impacted by surface transportation and industrial sources of noise. Some of the control techniques are presented here merely as suggestions to those involved in planning new housing. In any case, no simple rules can be devised regarding application of specific measures to certain types of applications, and the discussion is kept general in scope. It should be noted that the following discussion does not apply to noise control for aircraft over flights. This topic is discussed in Chapter 14.

2.0 THREE STEPS INVOLVED IN IMPLEMENTING NOISE CONTROL MEASURES

The process of implementing noise control measures for new housing can be viewed as a three-step process.

Step 1: Determination of noise levels at site;

Step 2: Comparison of projected noise levels against sound level limits; and

Step 3: Design of noise control measures for excess over sound level limits.

In Step 1, the noise levels at the proposed residential development is determined by the use of prediction models and techniques covered in Chapter 7. However, when the subdivision geometry or topography is complex and the area is impacted by many different types of noises, prediction methods cannot be readily applied and measurement techniques give more reliable information.

Measured levels are projected to future years (usually 10 years hence) in order to fully appreciate the potential impact.

Having determined the future noise levels for the proposed site in Step 1, these are compared against the outdoor sound level limits given in Chapter 6, and the excess over recommended limits is determined. Of course, if the levels at the site are lower than these limits, no noise control measures are required.

Step 3 involves selection of appropriate noise control measures depending on the following factors:

(i) Required reduction of indoor and/or outdoor levels.

(ii) Timing for considering noise control measures in the subdivision design process, i.e. early or late.

(iii) Constraints or restrictions unique to the site.

It must be pointed out that there are certain minimum noise control requirements. The details of the procedure are presented in Chapter 14.

3.0 SIGNIFICANCE OF TIMING IN CONSIDERING NOISE CONTROL MEASURES

The earlier discussion in Chapter 6 identified two different design sound level limits to be met in designing new housing, applicable to indoor noise levels and outdoor noise levels. Although the implementation of noise control measures outdoors also affects the levels achieved indoors, generally speaking, these measures can be viewed as relating to two separate applications. Table 8.1 groups commonly used noise control measures under these two categories. Measures in the Table are also grouped on the basis of whether they can be considered during the early or late stages of planning the subdivision. The Table clearly indicates that the earlier noise control is considered during the process of subdivision design, the larger the selection of available control measures there will be to choose from. Thus, early consideration of noise control can conceivably reduce the costs of noise control by selecting measures which are most economical and also at the same time satisfy aesthetic and other requirements.

Physical methods to reduce noise impacts on new housing can be grouped into four major categories, as shown in Table 8.2.

1. Site planning
2. Acoustical barriers
3. Architectural design
4. Construction techniques

A discussion of each group follows.

Noise Control Measures

Measures to Reduce Outdoor Noise Levels

Early Consideration in Planning Process

- Distance setback
- Insertion of noise insensitive buffer zones
- Orientation of outdoor living areas
- Favourable topographical features as barriers
- Earth berms
- Barrier walls and fences
- Intervening structures as barriers
- Orientation of balconies and terraces

Late Consideration in Planning Process

- Earth berms
- Barrier walls and fences

Measures to Reduce Indoor Noise Levels

Early Consideration in Planning Process

- Blank walls
- Room and cooridor arrangement
- Orientaion of windows
- Acoustical treatment of walls, windows, doors and roofs
- Airconditioning and ventilation
- Orientation of balconies and terraces

Late Consideration in Planning Process

- Blank walls
- Room and cooridor arrangement
- Orientaion of windows
- Acoustical treatment of walls, windows, doors and roofs
- Airconditioning and ventilation

NOTE:

1. Outdoor noise control measures also generally reduce the indoor noise levels.
2. Measures considered during early planning process are generally more acceptable aesthetically and less costly.

Table 8.1. Indoor and outdoor noise control measures and the timing of their application in the subdivision planning process

Noise Control Measures

Site Planning	Acoustical Barriers	Architectural Design	Construction Techniques
● Distance setbacks ● Insertion of noise insensitive buffer zone ● Orientation of outdoor living areas	● Favourable topographical features as barriers ● Earth berms ● Barrier walls and fences ● Intervening structures as barriers	● Orientation of balconies and terraces ● Room and corridor arrangement ● Orientation of windows ● Blank walls	● Acoustical treatment of walls, windows, doors, and roofs ● Air conditioning and ventilation

<u>NOTE:</u>

For design purposes, vegetation, plantings and trees should not be considered as being acoustical barriers

Table 8.2. Summary of noise control measures applicable to design of new housing

4.0 ACOUSTICAL SITE PLANNING TECHNIQUES AS NOISE CONTROL MEASURES

Site planning means making use of the natural shape of the site, favourable surroundings and zoning to reduce the noise impact on proposed housing. The natural features of the site can only be utilized in reducing noise levels if noise control is considered early in the planning of the subdivision, when the flexibility is still available. In general, site planning measures are economical and very effective. Experience indicates that prudent and cost-conscious planners and architects almost never fail to capitalize on the use of site planning techniques.

4.1 Distance Setback

Distance setback means the physical separation between the noise source and the receiver is increased to reduce outdoor noise levels. This method is most effective close to the noise source. For example, increasing the distance of a receiver from a highway from 20 m to 40 m would attenuate hourly Leq levels by approximately 4 dBA. On the other hand, if the receiver were located at 80 m, to get the same attenuation, the distance will have to be increased to 160 m. This is because the sound decay rate of a source varies logarithmically with the distance.

Although the above illustration is given for highway noise, the decay rate of sound also applies to railway noise.

Noise reduction by distance setback is usually more practicable in rural areas where land costs are lower. In most urban areas land is expensive and distance setback alone can rarely be afforded, unless the intervening land can be used for other compatible uses.

Distance setback as a measure to reduce outdoor noise levels is available only during the earliest of stages in a subdivision design when flexibility in planning design can still be exercised.

Distance setback is aimed at reducing outdoor levels.

4.2 Insertion of Noise-Insensitive Buffer Zones

The use of the distance setback method in urban areas is prohibitively expensive. It can, however, be made feasible if the setback strip can be put to other useful applications. Noise control by the use of a buffer zone is based on this concept. This approach offers two advantages; firstly, the setback area is utilized for a compatible land use. Secondly, additional shielding of the subdivision against noise may be provided if the buffer zone utilization calls for tall and continuous structures. This second advantage will be discussed in Chapter 9.

Typical land uses of the buffer strip are parking, parks, green belts and, in some cases, basketball and tennis courts. Commercial establishments such as shops, storage facilities, offices, etc. can be used as buffer zones. One such application is illustrated in Figure 8.1, the option to reduce outdoor noise levels by creating a buffer zone (i.e. a parking lot). Such design is available only during the early planning stage of the subdivision.

4.3 Orientation of Outdoor Living Areas

The requirement to provide quiet outdoor living areas for new residential development is as important as ensuring low noise levels indoors.

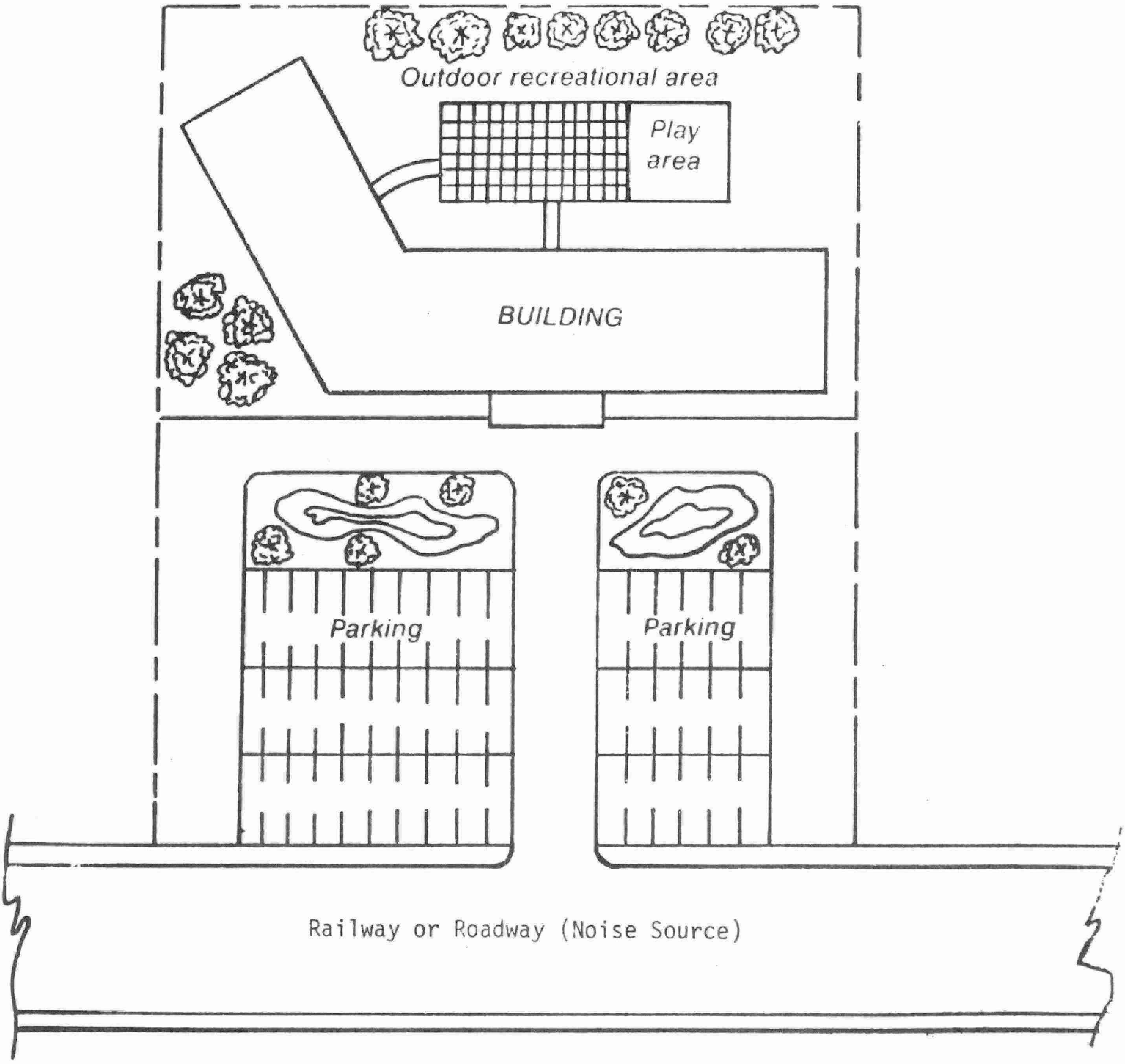


Figure 8.1. The use of parking area as a noise-insensitive buffer zone

The backyards of dwellings are customarily used as private areas for the enjoyment of the outdoors and for passive activities such as relaxation, conversation, etc. while the front yards are usually for parking. In some cases, the house structure itself can act as a barrier between the noise source and the receiver by shielding the backyard from noise. The closer the houses, the larger the shielding. Shielding of the backyard is more effective for linkhousing, rowhousing or townhouses where the structure is continuous, parallel and close to the noise source. Short length structures of single family units are not very effective as barriers.

Two common ways of planning quiet outdoor living areas are listed below.

In one arrangement the front yard of the townhouse is located directly exposed to the noise source and the backyard in the shadow zone behind the residence. Parking and entrance to the townhouse is provided through the front yard, as shown in Figure 8.2. This application is known as single side use, internal road. Another way of arranging the recreational area is to interchange the front yard and the backyard in the above configuration and then protect the backyard from the noise source by the use of a berm or wall as shown in Figure 8.3. The front yard is serviced by the internal road running parallel to the townhouses. The second arrangement is less efficient than the first one because of the added cost of erecting and maintaining the berm and because of aesthetic reasons. The function of a berm is performed by the townhouse structure itself in the first arrangement.

The methods of shielding the backyard as shown in Figures 8.2 and 8.3 are not without drawbacks. The concept of employing a continuous structure to shield

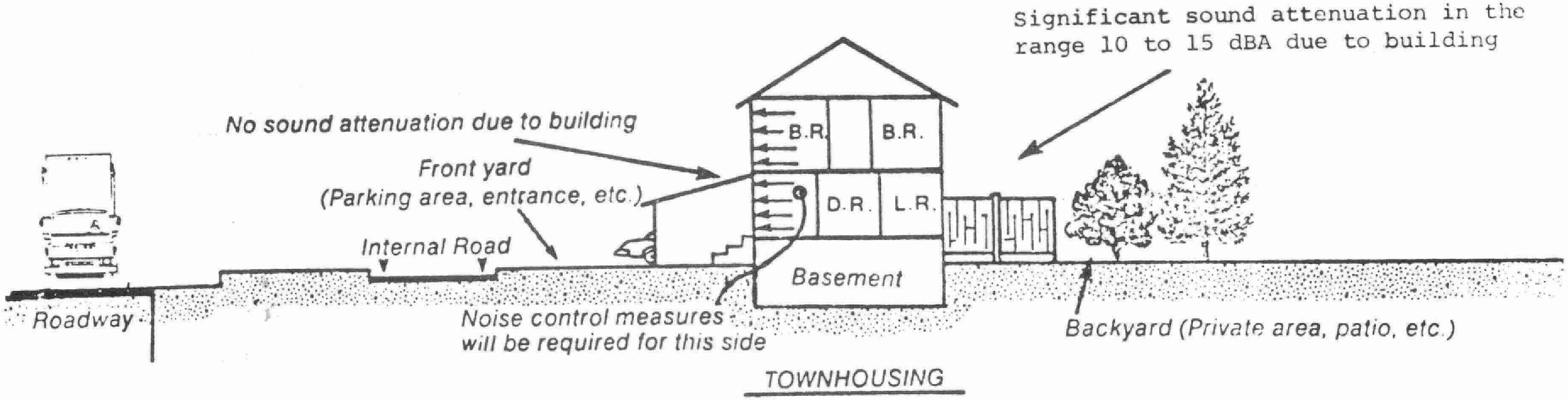


Figure 8.2. Recreational area (backyard) shielded by the townhouse structure

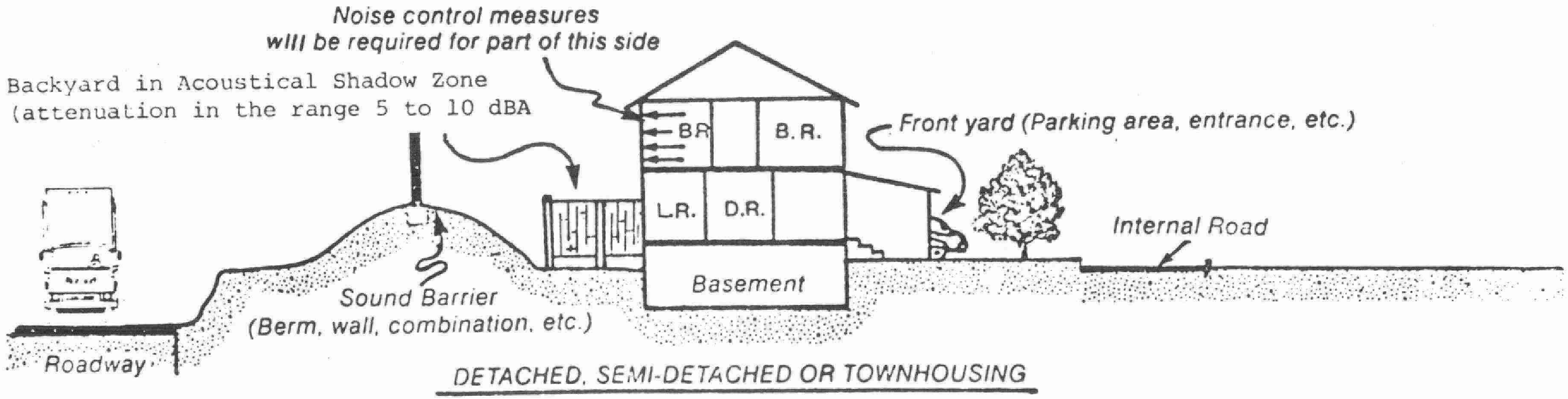


Figure 8.3. Recreational area (backyard) shielded by a sound barrier

backyards is a restrictive one, since only rowhousing or townhouses satisfy the requirement, precluding the use of single family homes in the first row. Planners also point out that the single side use of the internal road is inefficient and expensive because residences are located on one side of the road only. One answer to these problems is to use key lots for the exposed row.

Key lots are basically the back lots located behind the front lots and connected to the public street by a long and narrow driveway for vehicular and pedestrian access. In Figure 8.4 the internal road serves the key lots as well as the front lots. Zero lot line single family homes on key lots provide a near continuous structure shielding the backyards from the noise source. For effective noise control, gaps between the single family homes should be minimized. Finally, it must be recognized that because of the gaps being present in the exposed row, noise reduction in the backyards of key lots will be less than that provided by a continuous row of townhouses and/or rowhouses.

It is reported* that in spite of the relatively long driveways which impose an additional burden on snow removal on the occupant, per unit servicing costs for key lots are actually lower when compared with those of a conventional subdivision. The increased number of driveways and access roads, however, reduces the number of spots available for street parking. Further, it is harder for visitors to identify a key lot driveway. The planner must judge if the noise problem at the site is serious enough to be resolved at the cost of introducing these inconveniences.

Sale quadruplex, a new type of housing not widely in use, is a variation of key lot principle*. This concept

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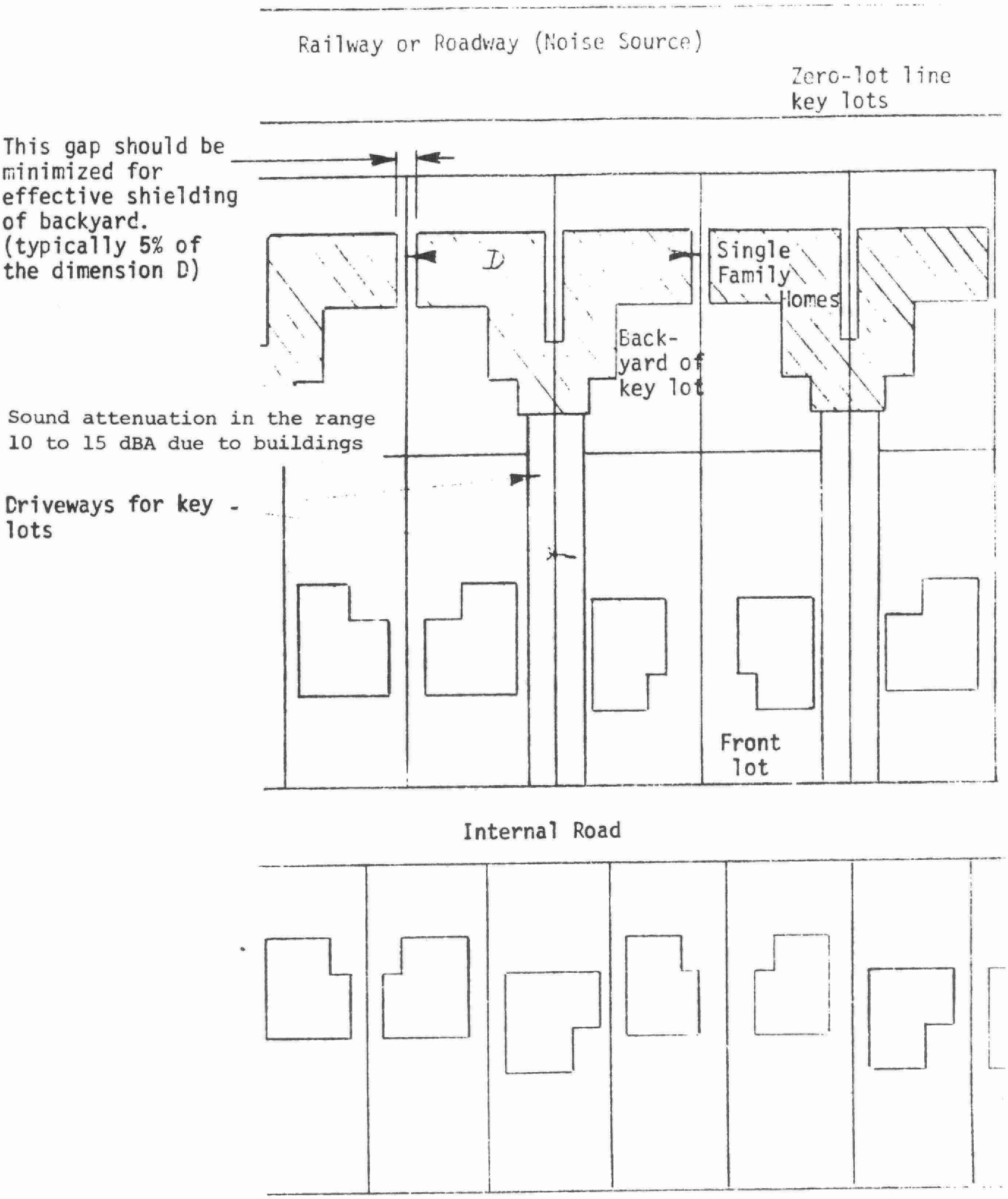
*Key Lot Study for the Townsend Community Development Program, Ministry of Housing, prepared by John Bousfield Associates, February 1977.



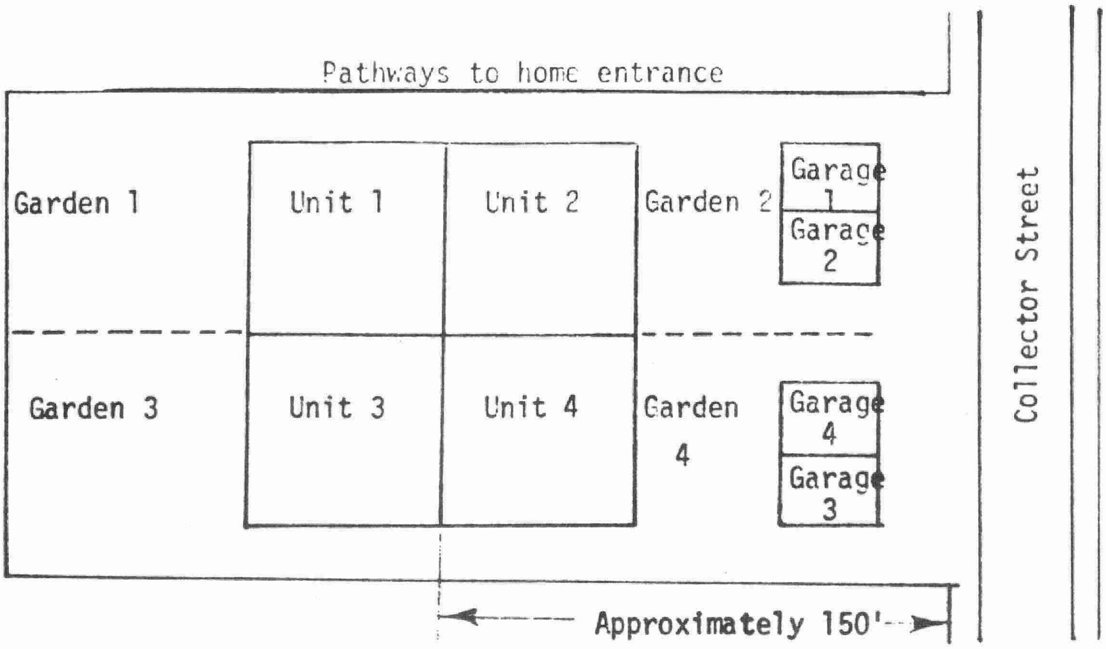
Reproduced from the Key Lot Study for the Townsend Community Development Program, Ministry of Housing, by John Bousfield Associates, February, 1977.

Figure 8.4. Single family homes (shown shaded) shielding recreational area

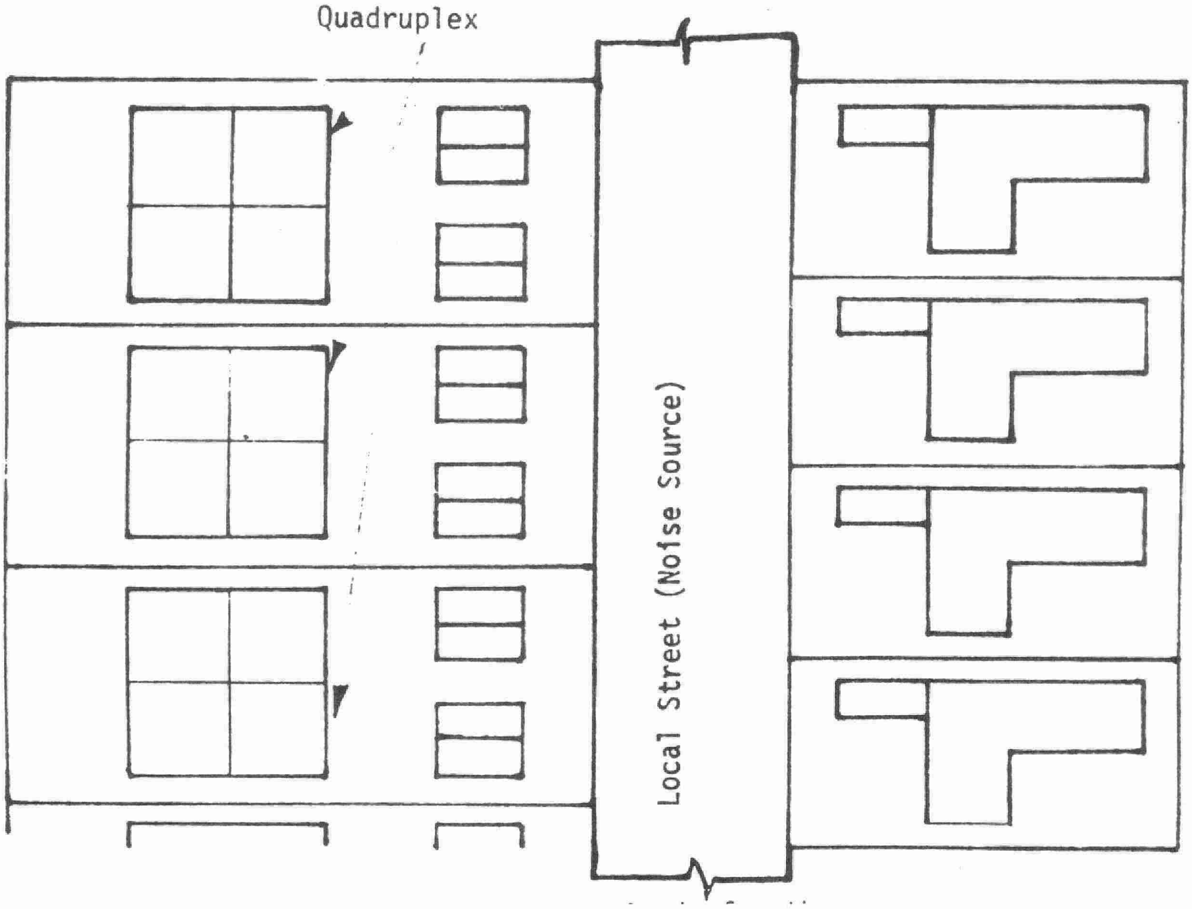
minimizes the length of driveways and provides a more direct access to the units as compared to key lots. In this arrangement, each lot is divided in four semi-detached dwellings. The gardens of the two front units are shielded from the noise source by the garage building, and the outdoor living areas of the rear units are well protected and far removed from noise as shown in Figure 8.5. However, because of the finite dimensions of the garage, the reduction of levels in the front yard cannot be expected to be large. As a result, the application of the quadruplex is limited to situations where only a slight noise reduction is required, such as for a lot exposed to a busy local street.

Figure 8.6 illustrates four of the ways of shielding outdoor living areas of apartment buildings, which were proposed for the St. Lawrence Housing Project, Toronto. In all four cases the building shields the outdoor living areas from the noise source. Another variation in which the outdoor living area of an apartment building is located on the third floor and can also be used as a sun-deck, as shown in Figure 8.7. The concept of shielding backyards is not just confined to more conventional forms of housing such as townhouses, rowhouses and detached homes, but also extends to other types of dwellings. In Figure 8.7(b) the backyard of a duplex is divided into two separate areas depthwise, one being used by the occupants living upstairs and the other by the occupants on the main floor.

The planning to lower noise levels in outdoor living areas by orienting the outdoor living areas and residences must



Sale Quadruplex Type of Housing



Based on the Key Lot Study for the Townsend Community Development Program

Figure 8.5. Sale quadruplex to shield recreational areas from a busy street

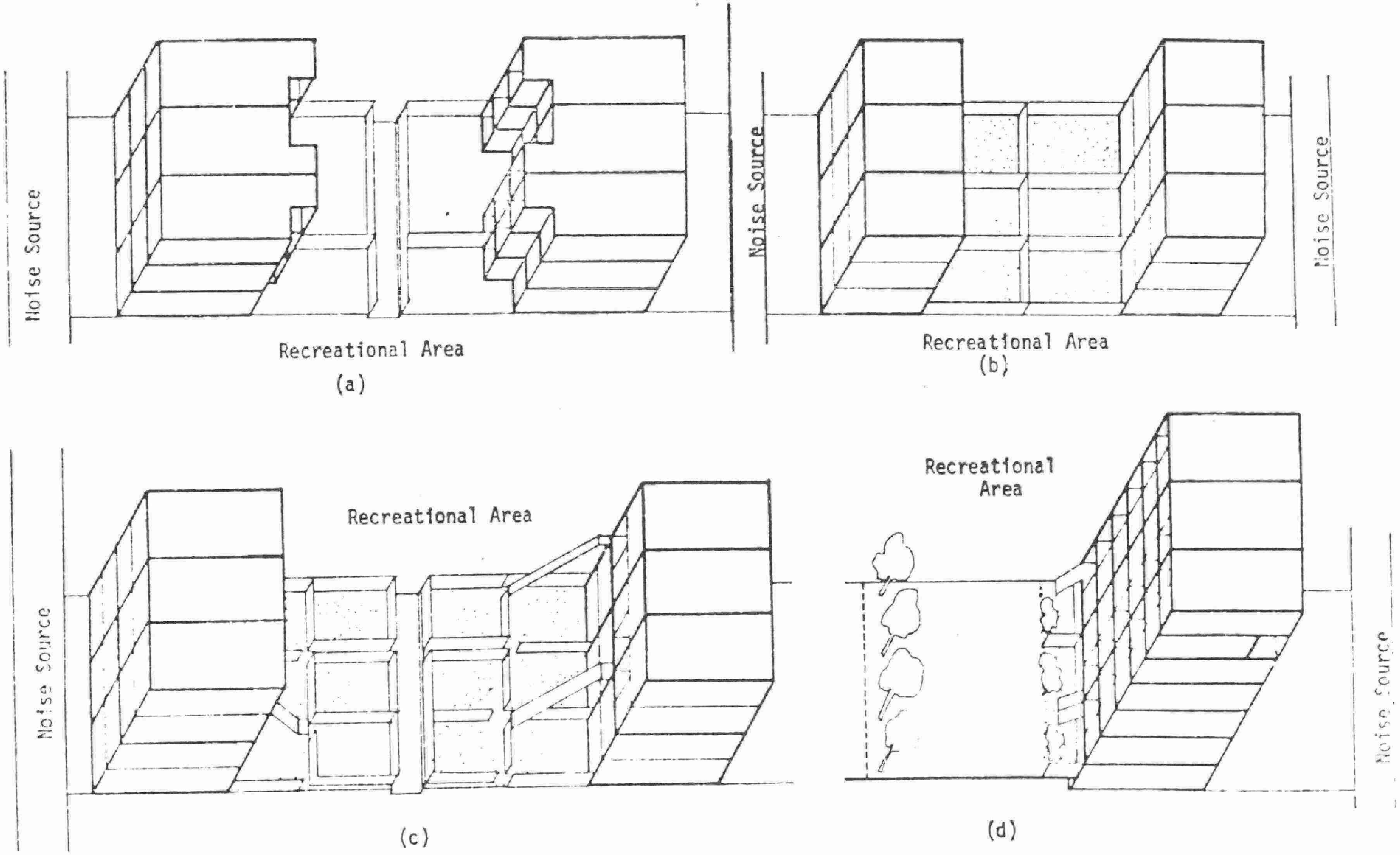
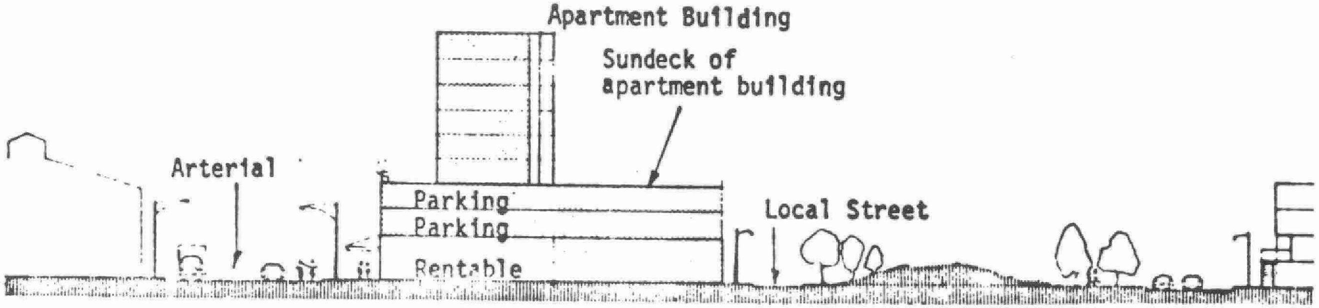
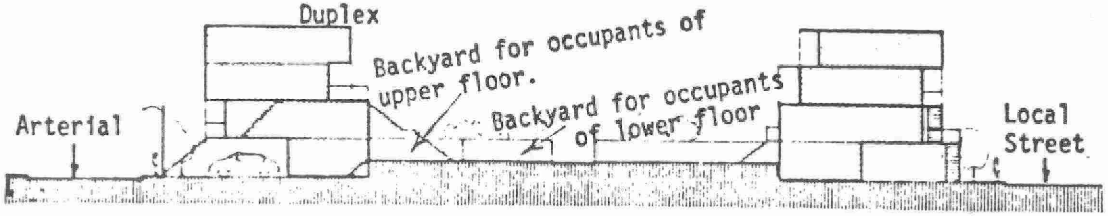


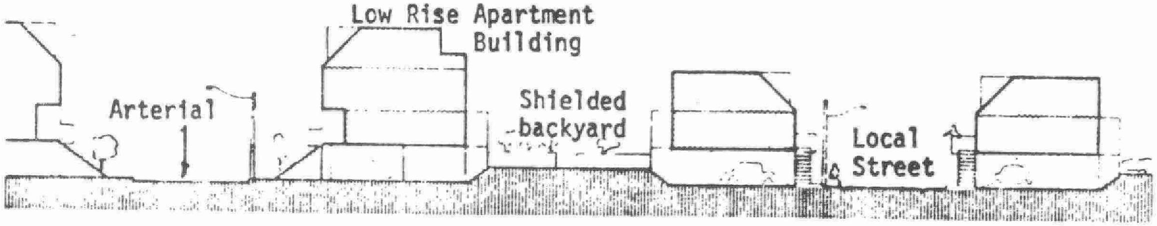
Figure 8.6. Shielding the recreational areas of apartment buildings proposed in the St.Lawrence Project, Toronto



(a) Planning a common recreational area of a high-rise building



(b) Planning recreational area of a duplex



(c) Planning recreational area of a low rise apartment building

These diagrams are reproduced from the reports on St.Lawrence Housing Project, The City of Toronto Housing Department.

Figure 8.7. Proposal to protect recreational areas for apartment buildings and duplexes for St.Lawrence Housing Project

commence early in the subdivision design process. The extensive use of this method by planners is a good indicator of the wide range of possible applications and economics of controlling noise.

5.0 ACOUSTICAL BARRIER AS A NOISE CONTROL MEASURE

An acoustical barrier is a physical structure, planned or natural, placed between a noise source and the noise sensitive area where reduction of noise levels is required.

Although well designed barriers are known to be very effective in reducing noise levels, they should be considered as a secondary measure after various other site planning measures have been considered for the site and have failed to reduce the outdoor levels to the design sound level limit. Barriers are usually considered in those applications where outdoor noise levels cannot be reduced by other methods. Since certain barriers, such as berms, require valuable additional land, it is good practice to consider them early in the planning process. However, barrier walls can still be designed late into the subdivision planning process, if necessary.

The subject of barriers is discussed in more detail later in Chapter 9 and is examined in a Workshop Session in Chapters 12 and 13, but some observations with respect to the use of barriers are in order here:

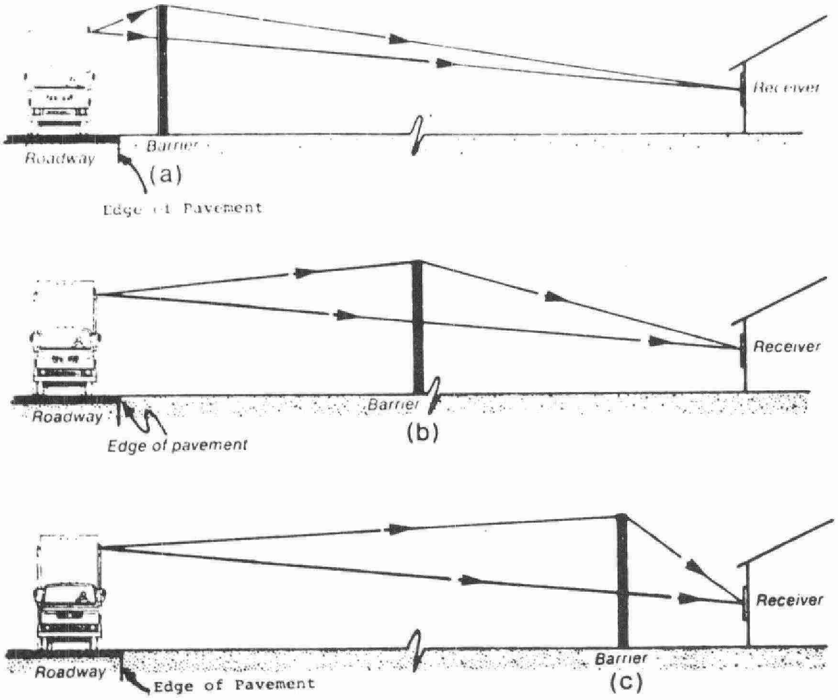
(i) To be effective, barriers must be long and continuous, encircling or surrounding the area to be protected so that sound waves do not pass around the ends. To ensure this the ends of the barrier are extended well beyond the noise sensitive area. The barriers must be solid, free

from gaps or holes and have adequate surface mass density [preferably not less than 20 kg/m^2 (4 lb/ft^2)].

(ii) Noise level reduction achieved due to a barrier is dependent on the path length difference, i.e. the difference between the direct distance in a straight line without a barrier and the distance measured over the top of the proposed barrier. The situation is illustrated in Figure 8.8. The barrier is most effective when it is erected either very close to the source or to the receiver. Another important design factor is the surface mass density of the barrier, denser barriers provide higher amount of noise reduction. However, the mass effect has a limit of diminishing return.

(iii) To be effective a barrier must be high enough to eliminate the direct line of sight between the source and receiver. A small amount of noise reduction is obtained even if the barriers do not block the line of sight. Highest possible elevations of source and receiver should be considered in the design calculations. Figure 8.9 illustrates this point for a receiver located at ground level as well as one at the first floor level.

(iv) If the barrier is properly designed, the noise problem can conceivably be minimized for the first row of sensitive receptors closest to the source and may be eliminated for the rest of the site, thus making a large portion of the site available for upgraded residential use which would not have been possible otherwise due to the hostile noise environment. As an illustration, appropriately designed rowhousing acting as a barrier may make

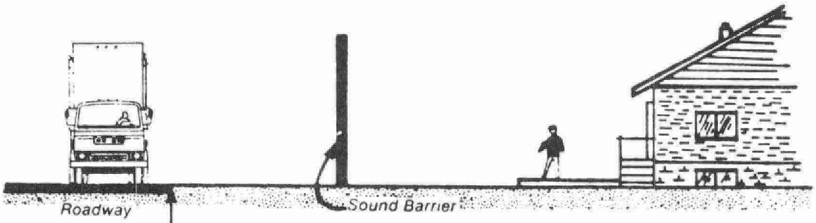


(a) Barrier close to source. Large path length difference. Recommended.

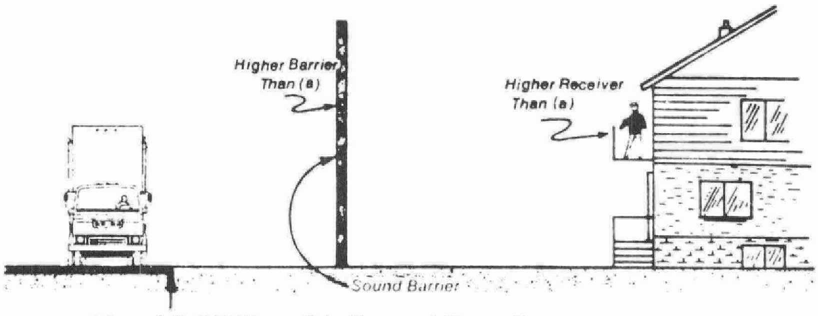
(b) Barrier half way between source and receiver. Small path length difference. Not recommended.

(c) Barrier close to receiver. Large path length difference. Recommended.

Figure 8.8. Possible sound barrier locations with respect to receiver and roadway



(a) Ground Floor Receiver



(b) Second Floor Receiver

Figure 8.9. Barrier height required for two receiver positions

it possible for single family houses to be planned for the inner core of the subdivision without any special noise control measures. Thus, the effect of erecting a barrier is to reduce the area impacted by excessive outdoor noise levels.

(v) Safety must also be considered in selecting a barrier design.

(vi) Structural stability and durability of the berm-barrier, servicing, maintenance, aesthetics and erection costs are other important considerations.

(vii) Snow removal is important on the noise source side.

(viii) Some added benefits of acoustical barriers should be noted such as privacy, providing visual screening, protection against salt, slush, debris and headlight glare.

A qualitative discussion of different types of barriers follows below; barrier calculations and quantitative aspects of barrier design are covered in Chapter 9.

5.1 Topographical Features as Natural Barriers

Existing topographical features such as valleys or ravines at a residential site can quite often be successfully exploited to act as natural barriers. Two such applications where direct line of sight between the source and receiver is eliminated and noise levels reduced by the use of favourable site topography are illustrated in Figure 8.10. In some cases topographical features can be enhanced or created at the site by excavating or landfilling or by lowering the road level.

Such natural barriers utilize the given features at the site, it readily blends with the topography of a site and is aesthetically more desirable. Costs also tend to be generally smaller compared to those for the erection of berms or barriers.

5.2 Earth Berms

An earth berm is a planned and deliberately created barrier usually made of a mound of earth running parallel to the noise source or the row of residences as shown in Figure 8.11.

Some important features of an earth berm are summarized below:

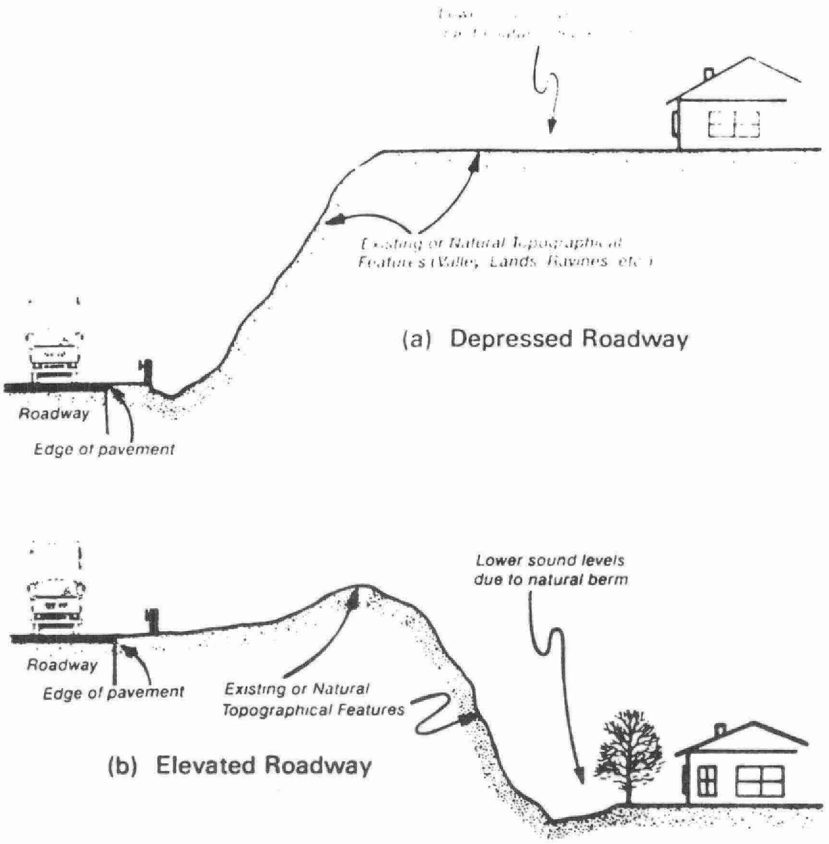
(i) Because of the sloping walls, the incident sound waves are deflected upwards and not towards the other side of the roadway as would be the case with vertical walls.

(ii) A berm provides a good absorptive surface compared to that offered by bare barrier walls, thus causing the levels of the reflected sound waves to be lower.

(iii) A berm easily meets the surface mass density requirement of 20 kg/m^2.

(iv) A berm can range up to 4 m, or more, in height and still be designed to be satisfactory from an aesthetic viewpoint.

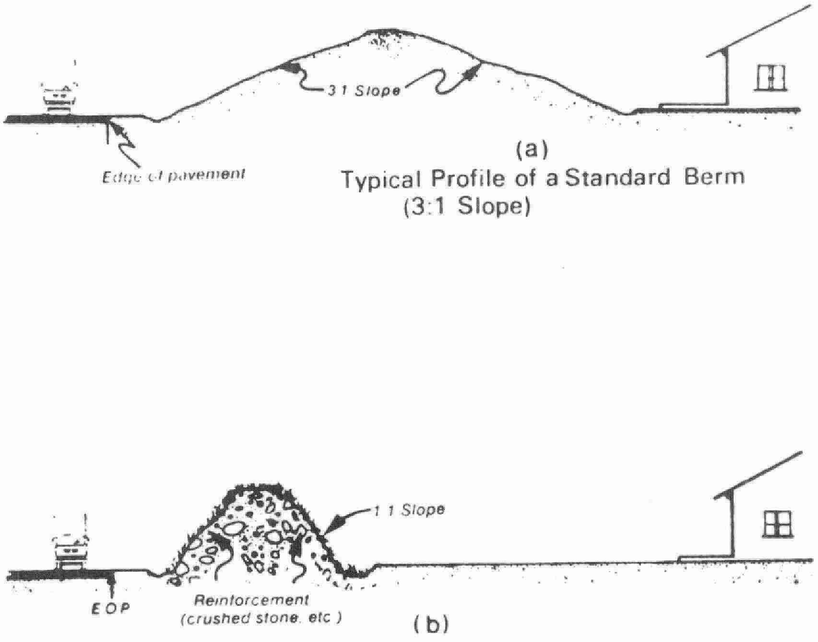
(v) The higher the berm the greater the volume of earth required for its construction, and the wider its base thus requiring more land for erection.



(a) Depressed Roadway

(b) Elevated Roadway

Figure 8.10. Lower sound levels created by existing or natural topographical features (reductions up to 20 dBA are possible)



(a) Typical Profile of a Standard Berm (3:1 Slope)

(b)

Figure 8.11. Typical profiles of specially designed berms

Since the erection of a berm requires land space, provisions must be made for it in the early planning stages. Shallow slope of a berm is aesthetically more acceptable, but also occupies more land and results in higher costs. High costs can be offset by successfully utilizing the slopes for various recreational purposes as shown in Figure 8.12.

Earth berms are specifically suitable to the problem of lowering noise levels in outdoor recreational areas, although indoor levels are also reduced to some extent.

Erection of berms as a control measure should be considered favourably if surplus earth were to become available during the construction of the subdivision at no cost. Cost of building berms includes erection cost, maintenance expenses of cutting the grass on slopes and snow removal expenses, etc. Structural stability and durability of the berm are also major design considerations.

5.3 Barrier Walls and Fences

Barrier walls or fences offer the advantage of requiring a minimum of space, easy maintenance and a very strong physical separation of the subdivision from the noise source. Walls may be used to supplement the height of a berm which cannot be built taller because of structural or space considerations. Another application of a barrier wall is to shield a site for which control measures were not considered in early planning stages and, later, the land available to erect a berm is found to be inadequate. Typical acoustical barrier walls are shown in Figure 8.13.

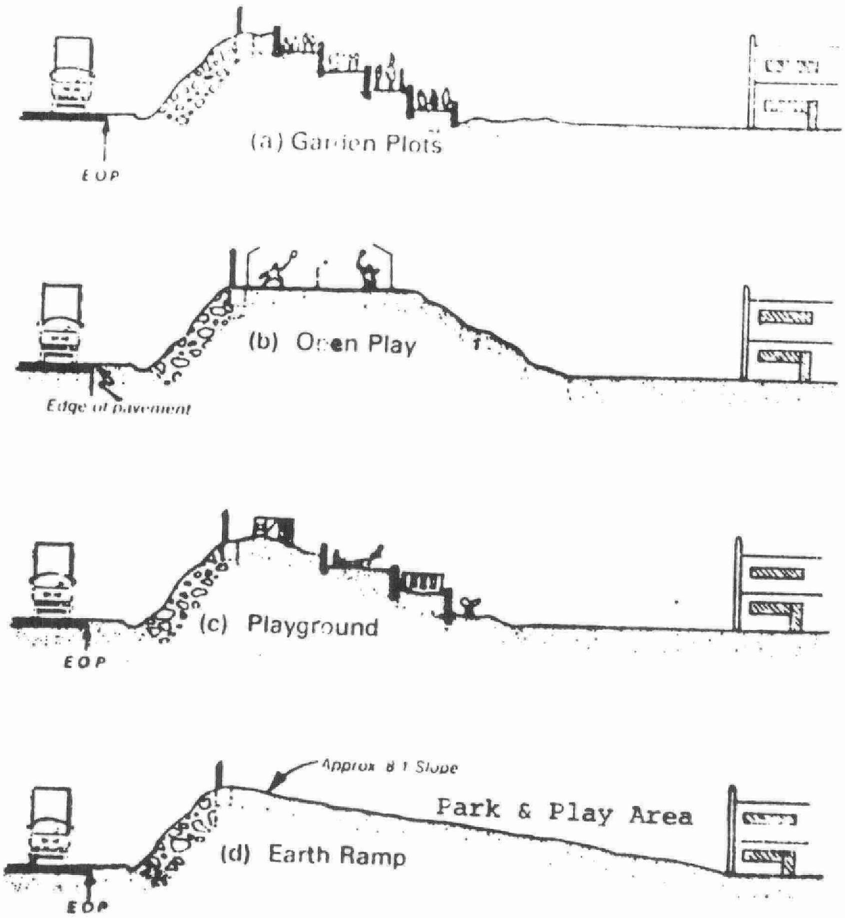


Figure 8.12. Typical applications for the slopes of earth berms

(a) Concrete Wall (Precast or Poured in Place)

(b) Brick Wall

Note: Gaps and Openings
Not Permitted

(c) Timber Wall

(d) Sheet Metal or Solid Wood Fence

Figure 8.13. Typical construction of acoustical barrier walls and fences

Acoustical barrier walls can be employed early, as well as late, during the planning process to control outdoor levels. To be effective the walls must be free of gaps and holes. Concrete walls are most commonly used followed by brick walls, timber and sheet metal fences. One major disadvantage of barrier walls is that they are aesthetically less acceptable than berms. Structural and stability considerations are especially critical in the design of high walls (higher than 3 m).

5.4 Intervening Structures as Barriers

In this method buildings located in the first row perform the function of the noise barrier for the rest of the site. The buildings so utilized are called barrier blocks.

Before we discuss barrier blocks for noise control we should differentiate clearly between this method and the method of orienting the outdoor living areas, the two methods are often confused with each other. By orienting the outdoor living area in a specific way, the planner aims at providing quieter outdoor living areas for individual units or blocks. This is accomplished by rearranging these units or blocks themselves. By using an intervening structure as a barrier, the aim is to provide quieter outdoor areas not just for the residences in the first row, but for the entire site. As an illustration, shielding the backyard of a barrier block itself is considered an exercise in the orientation of the outdoor living area, while the barrier block is considered as an intervening structure to shield the rest of the site.

Among the four noise control measures discussed under the heading of acoustical barriers, barrier blocks apply most widely, and offer the most creative and elegant answer to

the subdivision noise-impact problem. Some basic features of a barrier block are listed below:

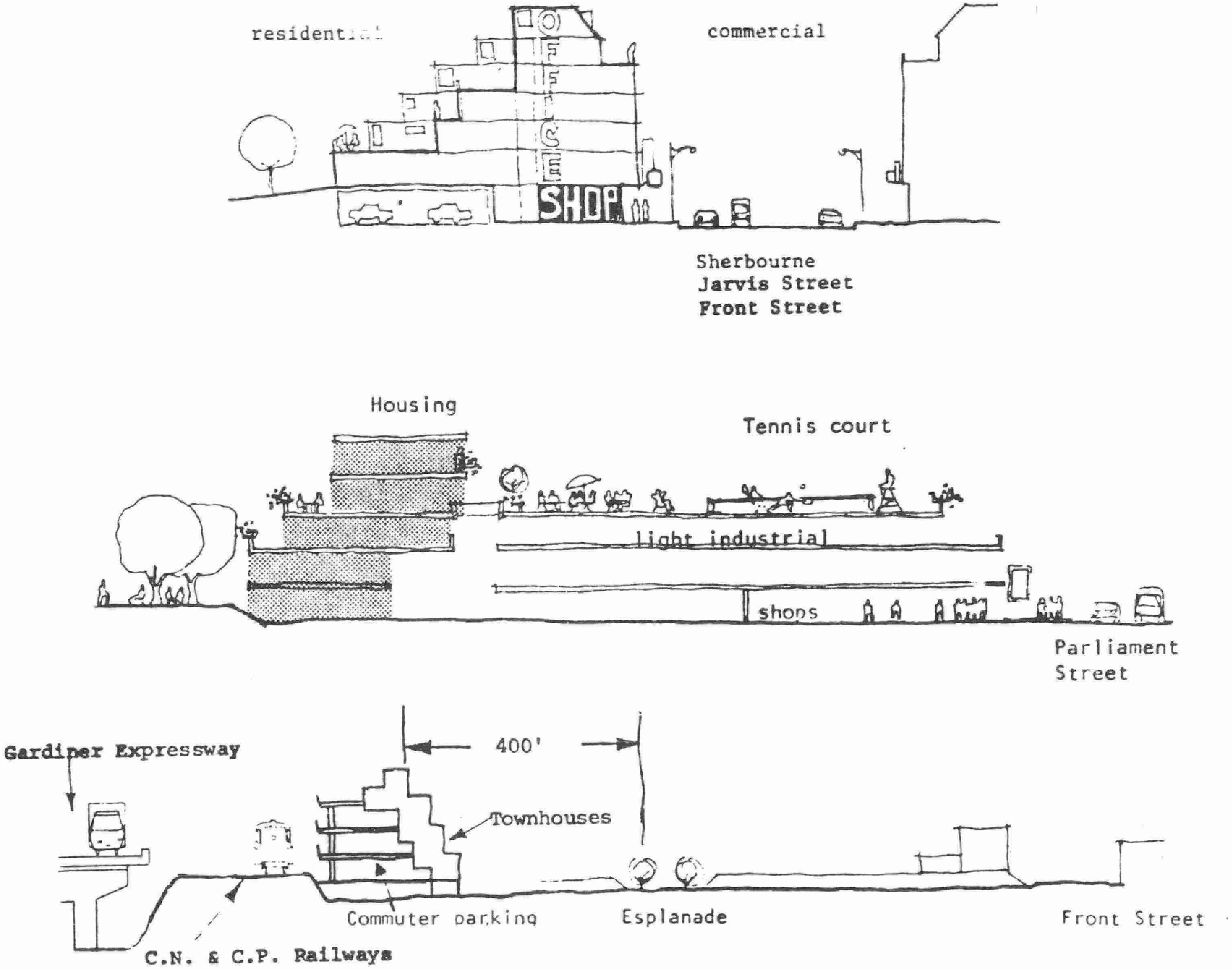
(i) It is a very economical measure, since the structure in the first row performs dual functions, one as the barrier to shield the site from noise and the other to house residential, commercial or other types of activity.

(ii) Since the planner has the choice to decide how the first row is to be utilized before it is actually built, this method offers high flexibility, provides an opportunity to ensure compatible land use and introduces interesting site diversity.

(iii) To be effective barrier blocks should be continuous and placed as close as possible to the noise source or the noise sensitive area. Thus, for a site directly exposed to the noise source, ideally the barrier block should abut the noise source. The passageways or gaps between the blocks to provide access or to fulfill fire control regulations must be minimized. Care must be taken to adequately protect the end blocks which normally have larger exposed wall areas then the inside blocks.

(iv) The barrier blocks are generally designed to be taller than the dwellings to be protected.

The widespread acceptance and use of the barrier blocks by planners and developers has resulted in many different configurations and variations being developed. Some of these arrangements are reproduced in Figure 8.14 from the St. Lawrence Housing Study. Figures 8.15 to 8.19 show commercial, industrial and medium density residential



(a) Barrier block as office space

(b) Barrier block as tennis courts, light industry and shops

(c) Barrier block as multi-story car park for residents

Figure 8.14. Some applications of barrier blocks recommended in the St.Lawrence Housing Project

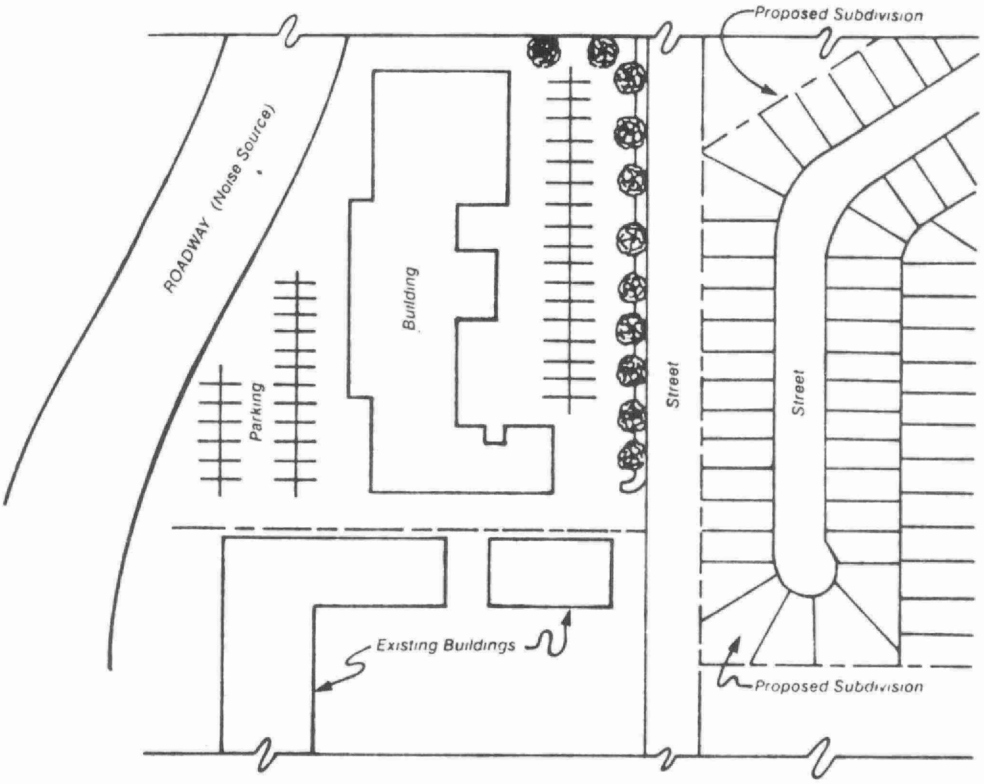


Figure 18.15(a). Commercial and industrial buildings as intervening structures

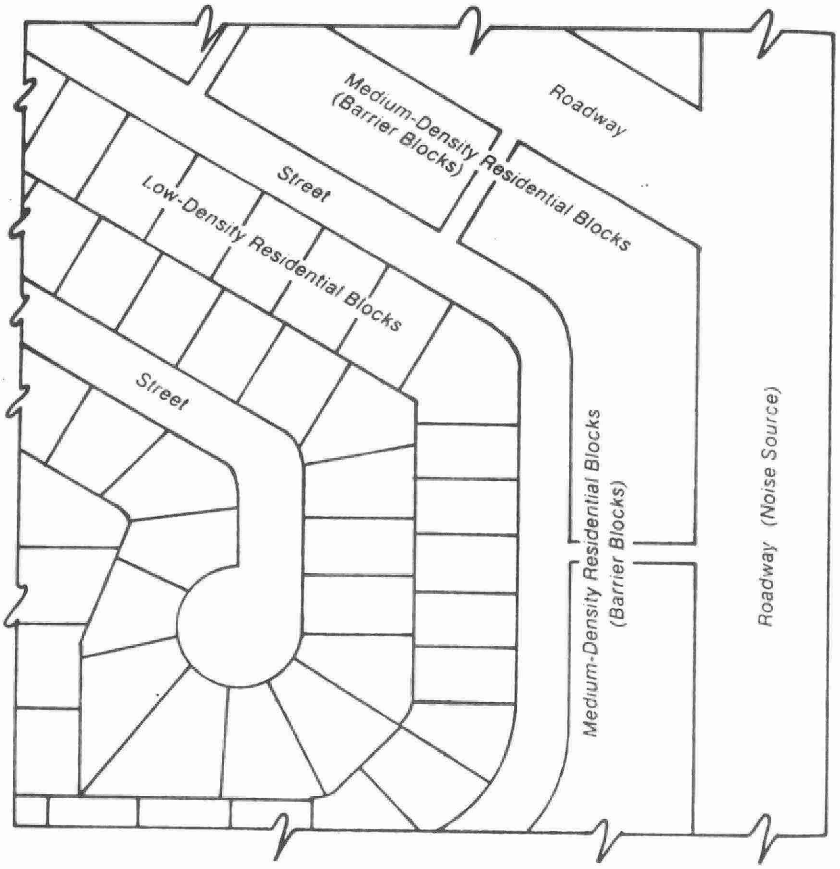


Figure 8.15(b). Typical mixed residential blocks as an intervening structure

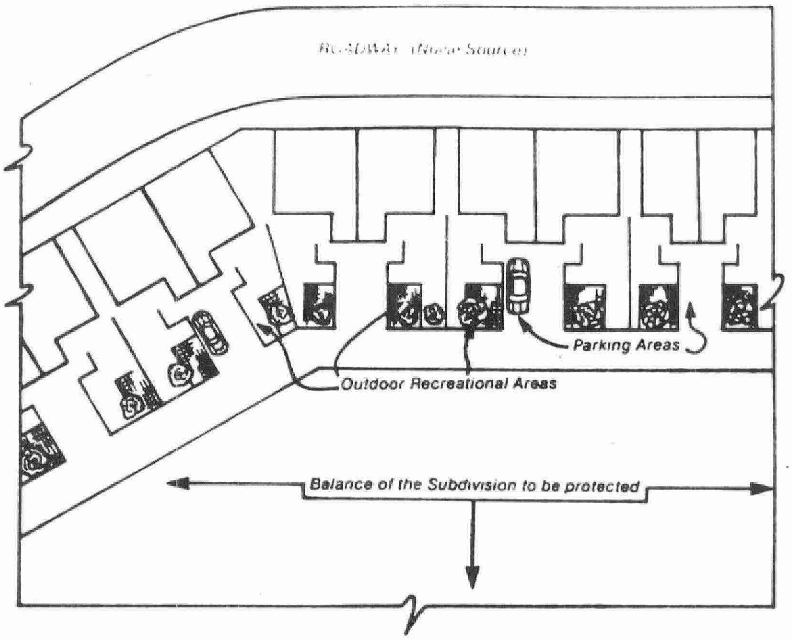


Figure 8.16. Turned in ends of barrier blocks

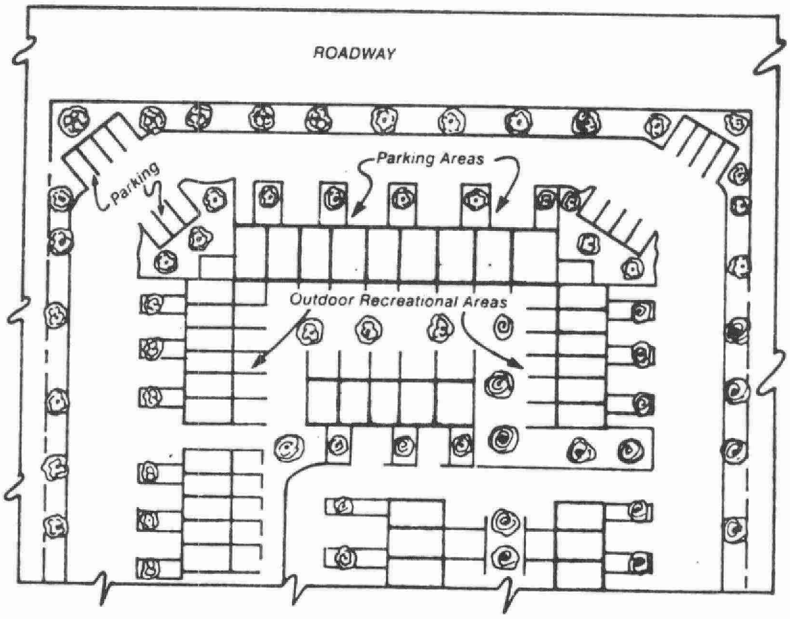


Figure 8.17. U-Shaped barrier blocks

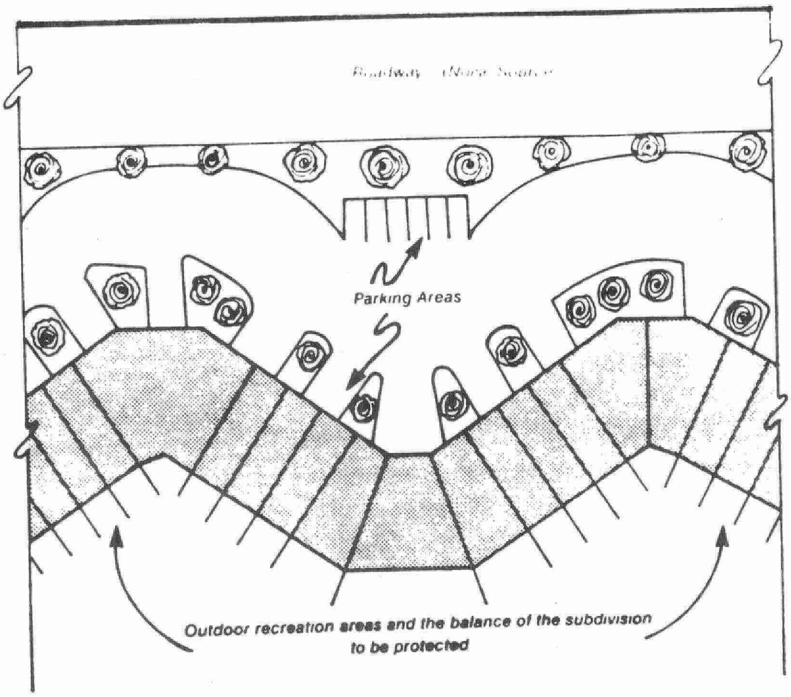


Figure 8.18. Zig-zag shaped barrier block

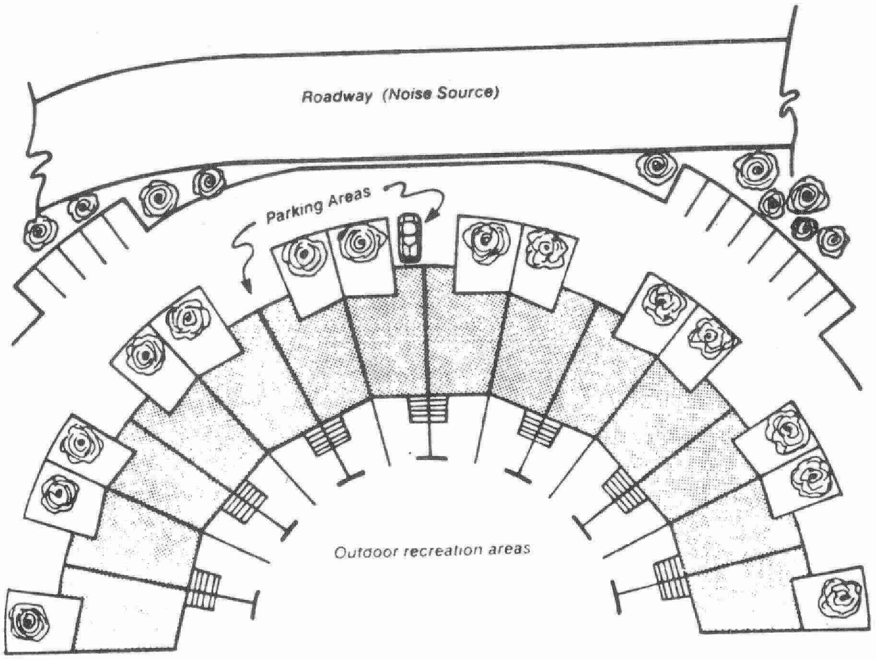


Figure 8.19. Fan shaped barrier block

buildings (townhouses) arranged in different ways along the periphery of a residential subdivision to act as a barrier block for the entire site. Reductions in the range of 10 to 17 dBA have been obtained.

The use of barrier blocks to solve noise problems is quite widespread and effective. The Ministry of the Environment highly recommends the use of barrier blocks to achieve economical and aesthetically acceptable outdoor noise control at the subdivision site. The planning for barrier blocks must begin early in the subdivision design process.

6.0 ARCHITECTURAL DESIGN AS A NOISE CONTROL MEASURE

The noise control measures discussed in this category are created and deeply influenced by the architectural design of the residential building. These measures are mostly employed to meet indoor noise level limits, although applications to reduce outdoor levels are also illustrated later. The four different types of architectural designs are discussed below.

6.1 Orientation of Balconies and Terraces

The concept used here is the same as discussed under the topic of orienting the outdoor living area in Section 4 with one difference. The earlier discussion applies to the outdoor living areas located on the ground level (such as backyards, patios, etc.), whereas this discussion concentrates on the outdoor living areas located at higher elevations. Examples of such areas are terraces of the high and medium rise apartment buildings and stacked townhouses which are more closely integrated with the architectural design of the residences than those discussed previously.

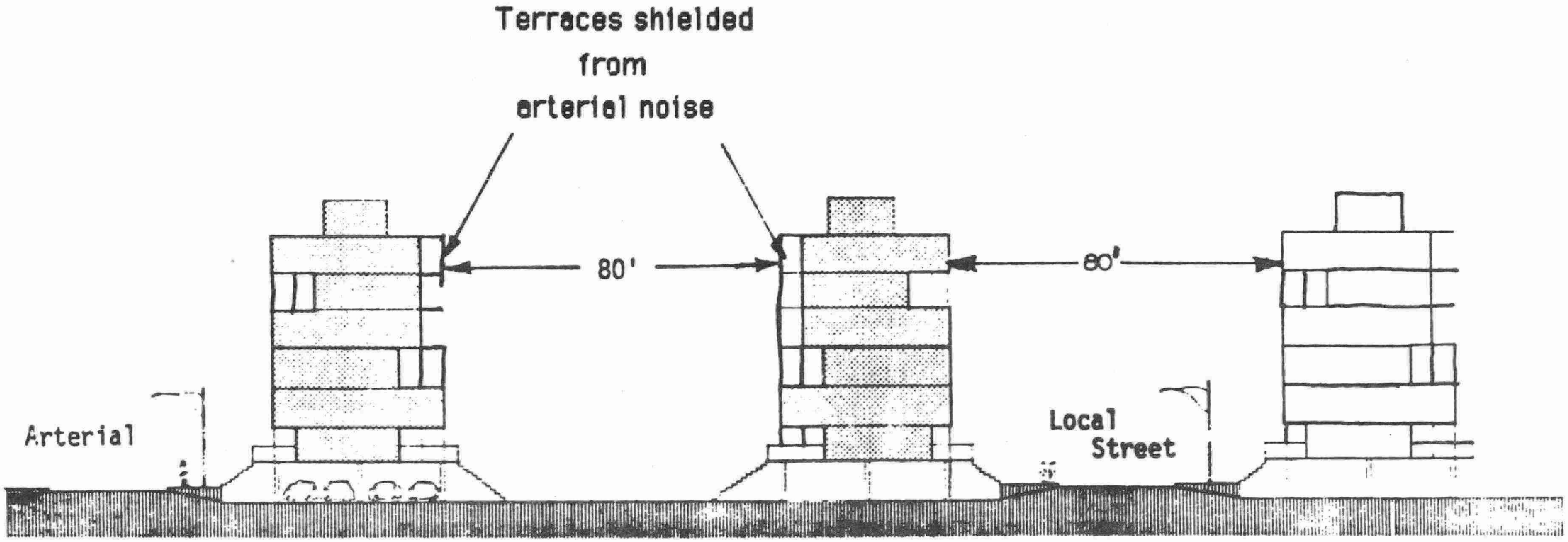
As with the backyards and the patios in the earlier case, the terraces are planned on the shielded side of the building. This solution, however, can only be applied to one side of a dual-aspect or double-loaded building because of the excessive noise exposure on the other side. Figure 8.20 shows a typical application for the St. Lawrence Project, in which the terraces are proposed on the quieter side of the apartment building.

Shielding of the outdoor area by locating it in the acoustical shadow of the building to reduce levels is an inexpensive measure easily adopted during the early planning stages.

Balconies and terraces must meet minimum noise standards if used as outdoor living areas. The details of the standards and guideline procedures will be presented in Chapter 14.

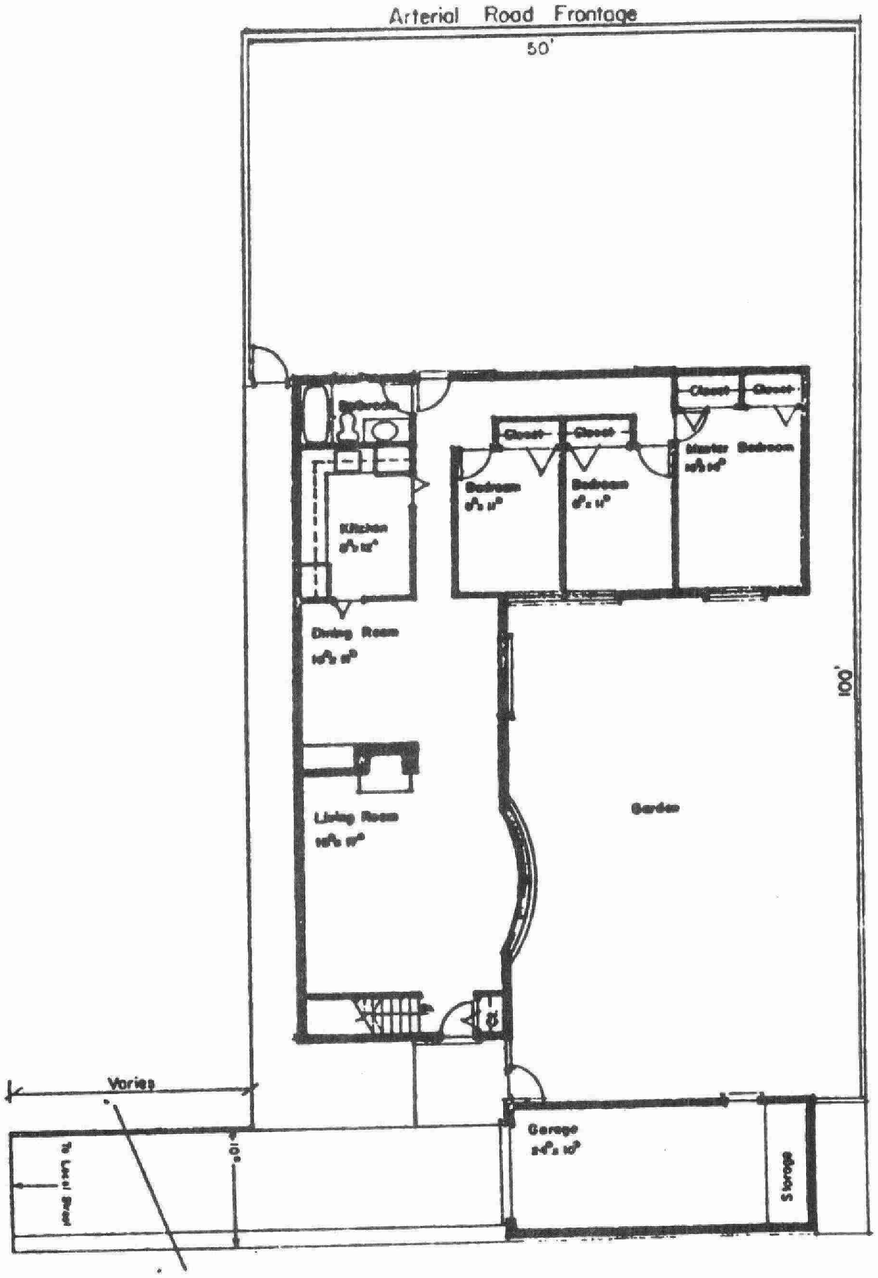
6.2 Room and Corridor Arrangements

Indoor noise levels in the noise sensitive areas of the home can be substantially lowered by arranging the less sensitive rooms and spaces adjacent to the exposed walls. The noise sensitive areas include bedrooms, living rooms and dens where sleep, speech communication and relaxation activities take place. By comparison, kitchens and bathrooms are considered to be less noise sensitive applications. Examples of uses which are not at all sensitive to noise are closets, storage rooms, corridors, stairways, etc. Figures 8.21 and 8.22 show two floor plans of detached homes designed specifically to reduce the indoor noise impact on residents. Also to be noted are the locations of the corridor, garage and kitchen in Figure 8.21 which are adjacent to the noise exposed walls.



Reproduced from the Report of the St.Lawrence Housing Project, City of Toronto Housing Department

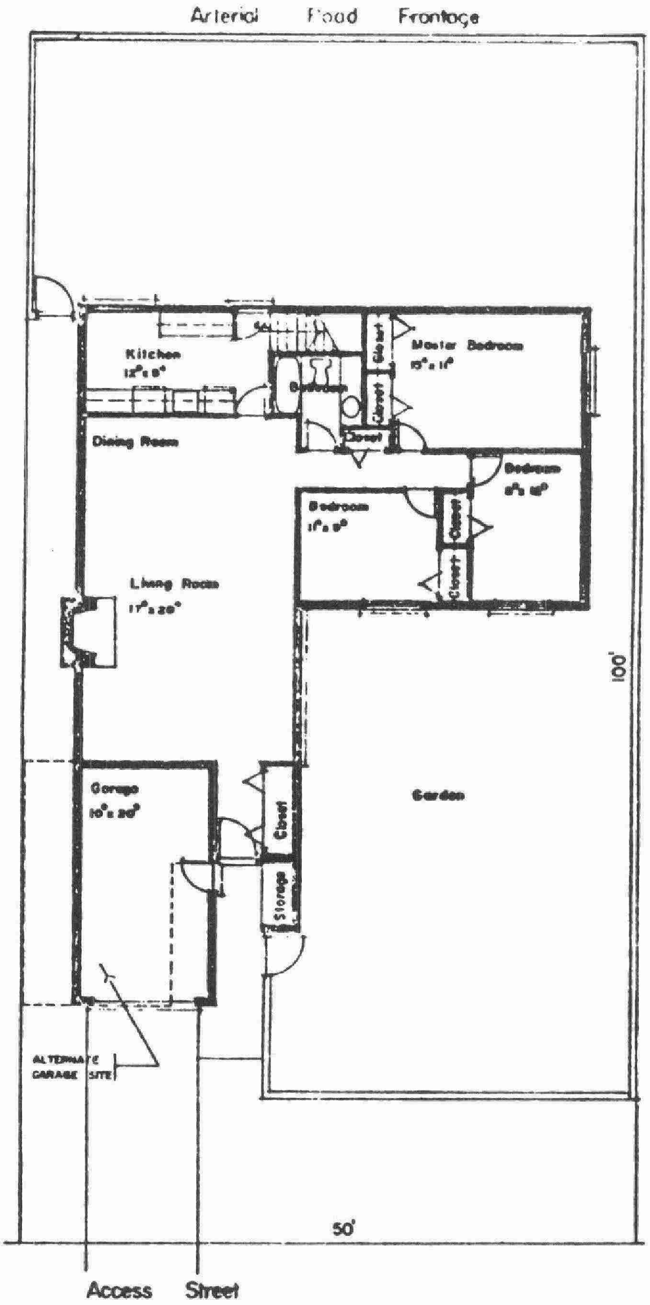
Figure 8.20. Orientation of terraces to provide shielding from noise



<u>NOTE:</u> The wall directly exposed to the road is used for noise-insensitive uses of bathroom, hallway and closets. Also, the windows open to the shielded garden.

Reproduced from the Key Lot Study prepared for the Townsend Community Development Program.

Figure 8.21. A proposed floor plan for the Townsend Program specially designed to reduce noise impact



NOTE: The noise-insensitive uses such as kitchen, stairs and closets arranged adjacent to the wall exposed to the arterial noise. To reduce indoor noise levels, windows are designed to face away from the road.

Reproduced from the Key Lot Study prepared for the Townsend Community Development Program.

Figure 8.22. An alternative proposal of a floor plan specially designed to reduce noise impact

With the use of good planning principles applied in the early stages of the floor-plan design, the problem of noise exposure of the occupants of the home can be effectively solved at practically no added cost.

6.3 Orientation of Windows

Indoor noise levels can be lowered by providing the windows on the walls which are not directly exposed to the noise source. In the house plans of Figure 8.21 and Figure 8.22 the windows of the bedrooms and the living room are arranged in the walls facing the garden and not the arterial road.

The effectiveness of this measure depends on the orientation of the wall with respect to the noise source. If the wall with the windows in it is parallel to the noise source on the shielded side of the house, significant reduction of indoor levels can be realized. For windows designed in the walls running perpendicular to the noise sources, the reduction is expected to be slight.

There is no added cost involved in orienting the windows on the unexposed walls. This measure is quite effective in controlling indoor levels and can be considered early as well as late during the planning process.

Consideration should also be given to the orientation of windows with respect to exposure to sunlight.

6.4 Blank Walls

From the noise insulation viewpoint, the window is the weaker link of a wall-window combination. For dwellings exposed to very high noise levels the exposed walls should be windowless. This is done by relocating the windows to

other walls subjected to lower noise levels. The blank walls find application in the high density housing (high rise apartments), stacked townhouses and also for the low and medium density housing (detached homes, townhouses, rowhouses, etc.). An example of the former is illustrated in Figure 8.23 where the apartment building wall facing the busy roadway is the blank wall and the windows are provided on the shielded side only. An example of indoor noise control by providing a blank wall for a townhouse is for a townhouse is shown in Figure 8.24. Similarly, the wall facing the arterial road in Figures 8.21 and 8.22 are for the most part blank walls.

The use of blank walls imposes two restrictions. The conventional house plan normally relies on openable windows located in opposite walls to provide adequate lighting and ventilation. With the use of one blank wall the flexibility to provide windows is somewhat reduced and care must be taken to ensure sufficient lighting and ventilation. One such alternative is to design units to be slightly wider than normal. The other restriction is that apartment buildings with one blank wall are "one side" loaded, resulting in the corridors, and passageways being under-utilized.

The application of blank walls should only be confined to the extreme cases where the noise problem is too serious to be resolved by other measures. The likelihood of poor lighting and ventilation dictates that this measure be used with the utmost discretion and only as a last resort.

Significant reduction of noise levels indoors is possible with the use of blank walls. The measure can be used early as well as late during the subdivision planning process. The cost of this measure may, in fact, range

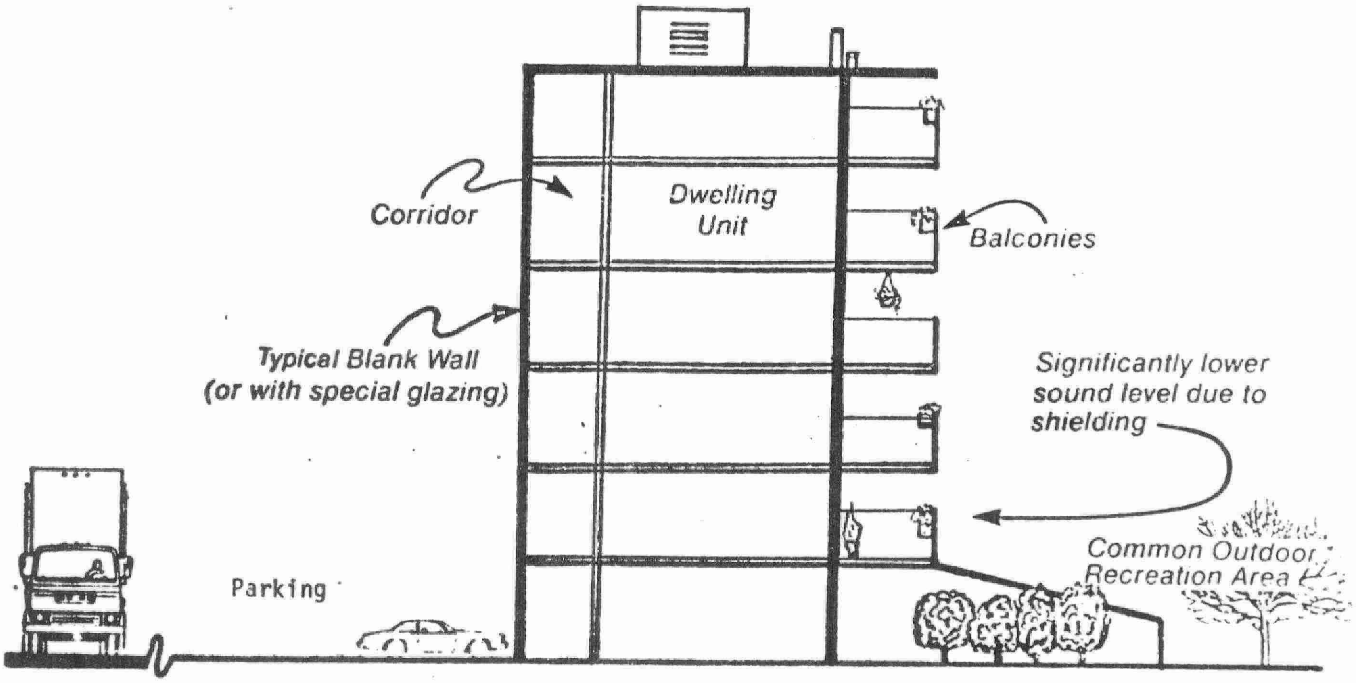


Figure 8.23. The use of blank walls for an apartment building or stacked townhouses

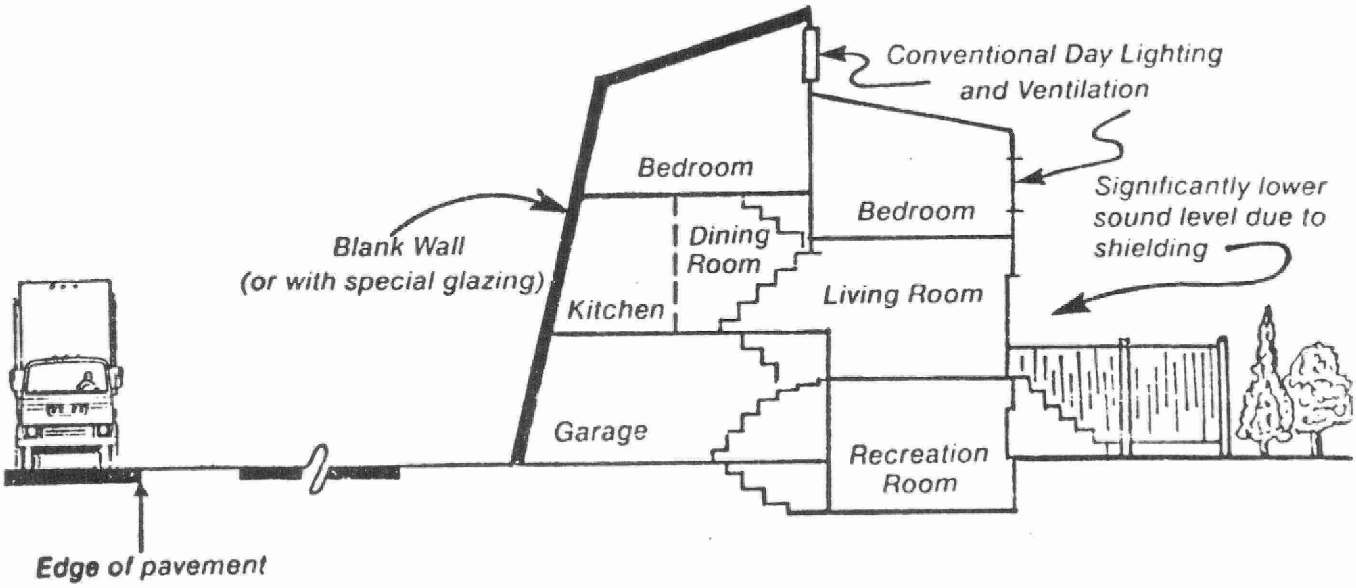


Figure 8.24. The use of blank walls for a townhouse

anywhere between slightly lower to somewhat higher than the cost of a wall window combination.

7.0 CONSTRUCTION TECHNIQUES AS NOISE CONTROL MEASURES

If indoor noise levels cannot be lowered sufficiently by the design of the architectural features, further reduction is possible by employing special construction materials and techniques. To minimize the cost of noise control these measures should only be considered after the various architectural features favourable to the noise reduction have been fully explored. The specific measures are discussed in Chapter 10.

8.0 CHECK LIST OF NOISE CONTROL MEASURES

So far we have discussed the various noise control methods for new housing, their recommended timing through the subdivision planning process, the cost factors and their advantages and disadvantages. In Table 8.3 the considerations will be summarized in the form of a check list for the use of the planners and architects. Although the check list is developed on a systematic and methodical basis, it can at best be offered only as a rational approach to solve the problem. Each subdivision development is unique, therefore, judgement, common sense and discretion must be used when applying this check list.

Measure	Application		Possible Timing of Application in subdivision planning process		Recommended Timing of Application in subdivision planning process		Remarks	
	Control Indoor Levels	Control Outdoor Levels	early	late	early	late	Cost considerations	Advantages /Limitations
site planning								
1. Distance set-back		✓	✓		✓		high	impractical for urban areas
2. Noise sensitive buffer zones		✓	✓		✓		slight to moderate	moderately effective, wide range of possible applications
3. Orientation of outdoor living areas (located on ground levels)		✓	✓		✓		very little or no cost	quite effective, highly recommended
acoustical barriers								
1. Favourable topographical features as barriers		✓	✓		✓		little or no cost	quite effective
2. Earth berms		✓	✓	(sometimes) ✓	✓		moderate to high	problems with visibility, maintenance, snow removal, etc. should be considered if spare earth is available at the site, aesthetically less acceptable
3. Barrier walls and fences		✓	✓	✓	✓	✓	high	maintenance and visibility problem. Cuts down on headlight glare, provides excellent and sharp physical separation.
4. Intervening structures as barriers		✓	✓		✓		very little or no cost	very effective, highly recommended

* Table concluded on next page

Table 8.3. Checklist of the noise control measures for new housing

Measure	Application		Possible Timing of Application in subdivision planning process		Recommended Timing of Application in subdivision planning process		Remarks	
	Control Indoor Levels	Control Outdoor Levels	early	late	early	late	Cost considerations	Advantages /Limitations
architectural design								
1. Blank walls	✓		✓	✓	✓	✓	little or no cost	places severe restrictions on conventional designs and can pose problems in providing adequate lighting and ventilation
2. Room and corridor arrangement	✓		✓	(sometimes) ✓	✓	✓	little or no cost	very effective for high noise level exposures
3. Placement of balconies and terraces (located at higher elevations)		✓	✓		✓		little or no cost	very effective, highly recommended
construction techniques								
1. Special acoustical treatment	✓		✓	✓	✓	✓	moderate to high cost	effective
2. Air conditioning and ventilation	✓		✓	✓	✓	✓	high cost	should be used as a last resort, discouraged due to energy conservation considerations

NOTE:

1. The sequence in which the noise measures should generally be considered is, site planning, acoustical barriers (natural topographical features and intervening structures), architectural design and, construction techniques, and acoustical barriers (earth berms and walls).
2. It is usually possible to meet indoor and outdoor noise level limits by little or no added cost, if noise impact is considered very early in the planning process.
3. This check-list attempts to rationalize the approach to the noise control problem. It is not claimed to be authoritative nor exhaustive, but merely offered here as a suggestion.
4. The qualitative cost considerations provided here enable a comparison to be made between the cost of two or more alternative measures.
5. The principles of noise control as applied to land use planning are relevant to the preparation of Official Plans as well as to the planning of subdivisions.

Table 8.3. Concluded.

9.0 CASE HISTORIES OF INTEGRATING NOISE CONTROL MEASURES IN THE SITE PLAN

The following cases, some of which are extracted from the files of the Ministry of the Environment, illustrate the way the noise control measures can be incorporated into new housing plans. This does not necessarily constitute an endorsement of the approach by the Ministry of the Environment, but simply demonstrates the practicability of the various measures and their potential applications by the planners and architects.

9.1 St. Lawrence Housing Project, Toronto

The St. Lawrence Housing Project is housing 10,000 people of all ages and income in an area near the Toronto Waterfront which is severely impacted by noise from the elevated Gardiner Expressway and the train activity of the main CN and CP rail lines. The proposal called for rowhouses and garages integrated with the berms and walls as intervening structures which are arranged so as to be almost continuous (Figures 8.25 and 8.26). The purpose of this arrangement is to protect the houses located inside the core area from noise. It should be noted that erection of a continuous berm also provided the same noise attenuation but not offering nearly so diverse, interesting and aesthetically acceptable a site plan, as the use of the various illustrated techniques do.

9.2 Townhouse Development Exposed to Train Noise

This is a case history from the files of the Ministry of the Environment. Townhouses were planned for a subdivision located on Harris Avenue, in a location exposed to train noise. Initially, the site plan was prepared without due consideration to the noise control measures,

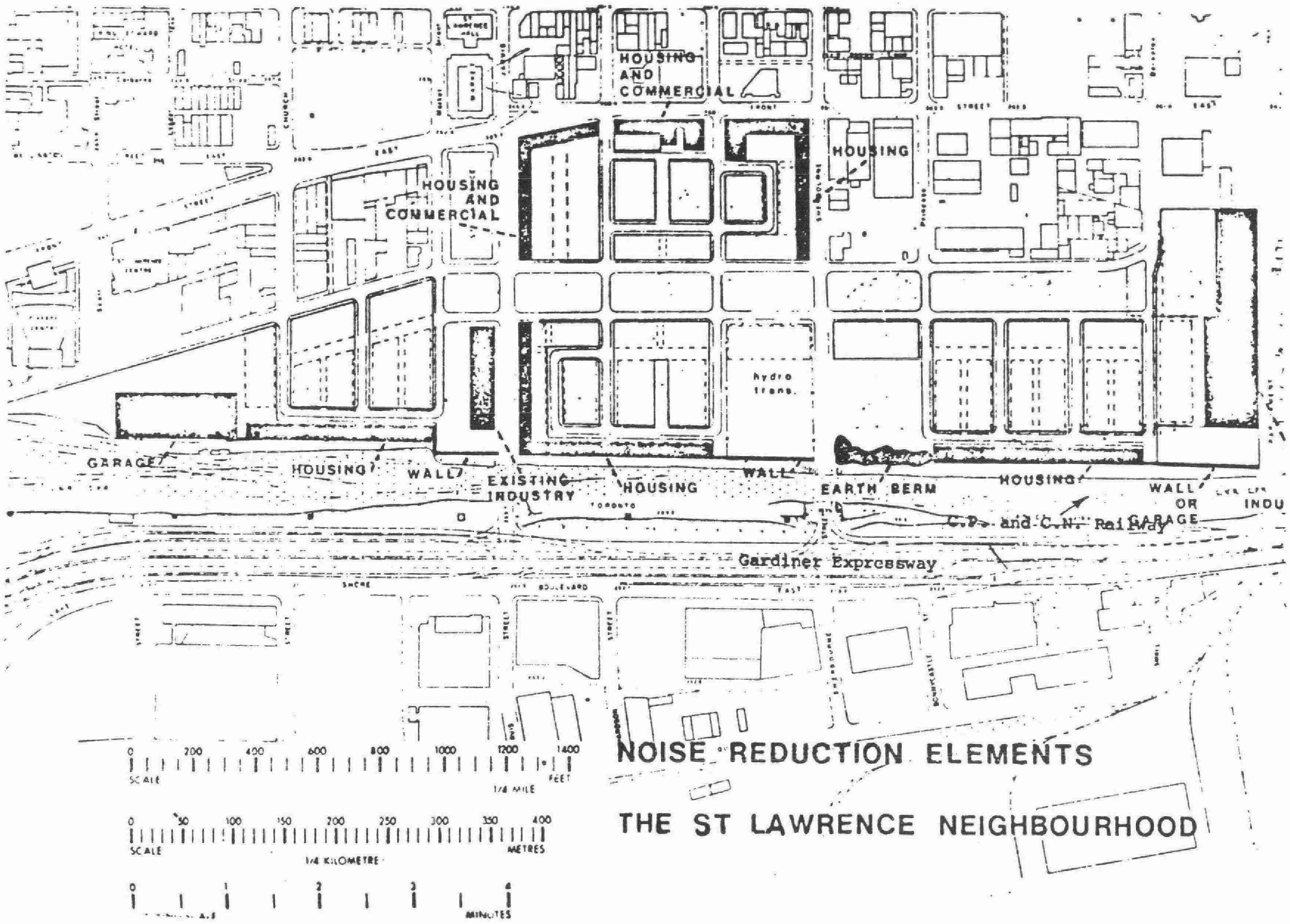
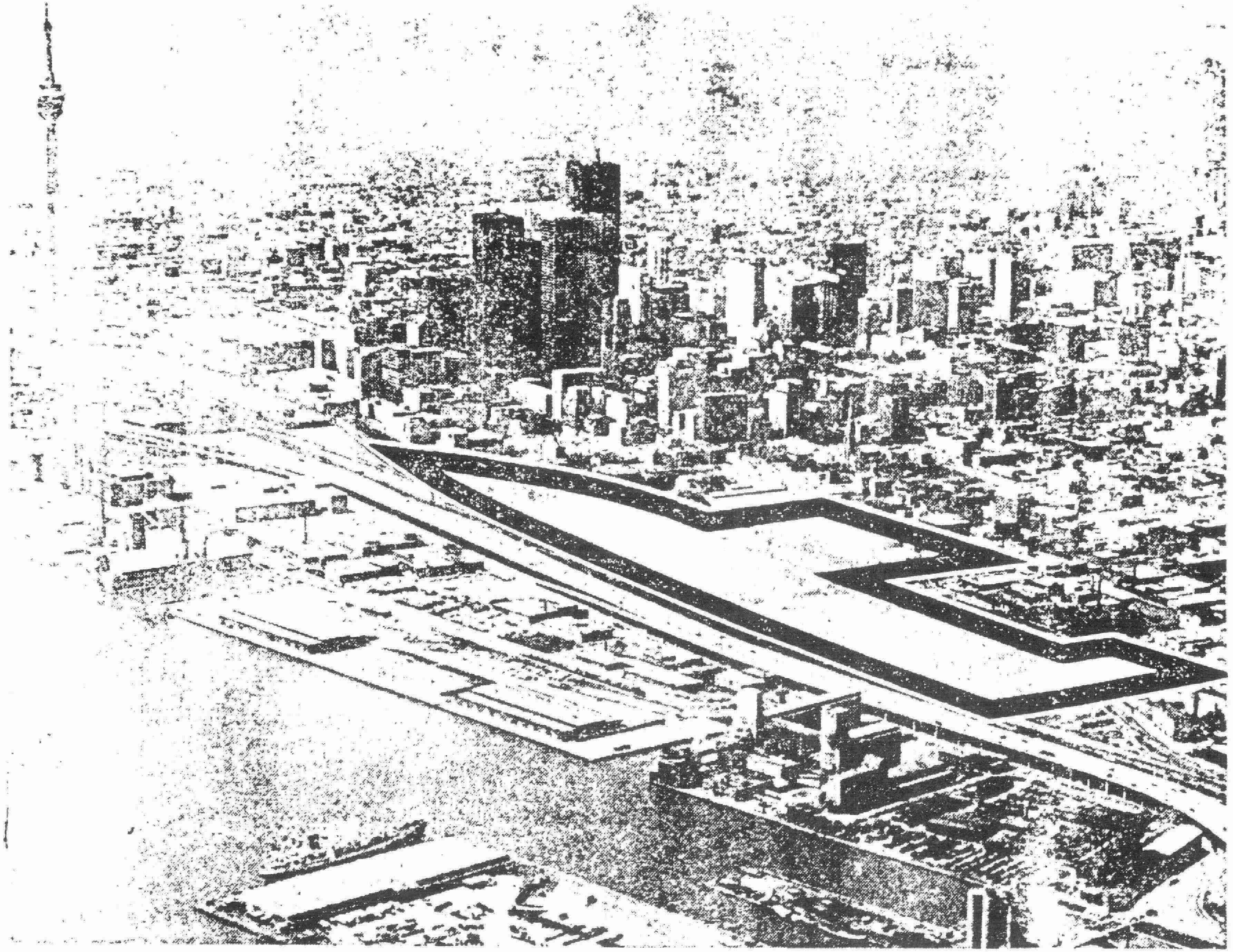


Figure 8.25. Noise control measures proposed for the St. Lawrence Housing Study

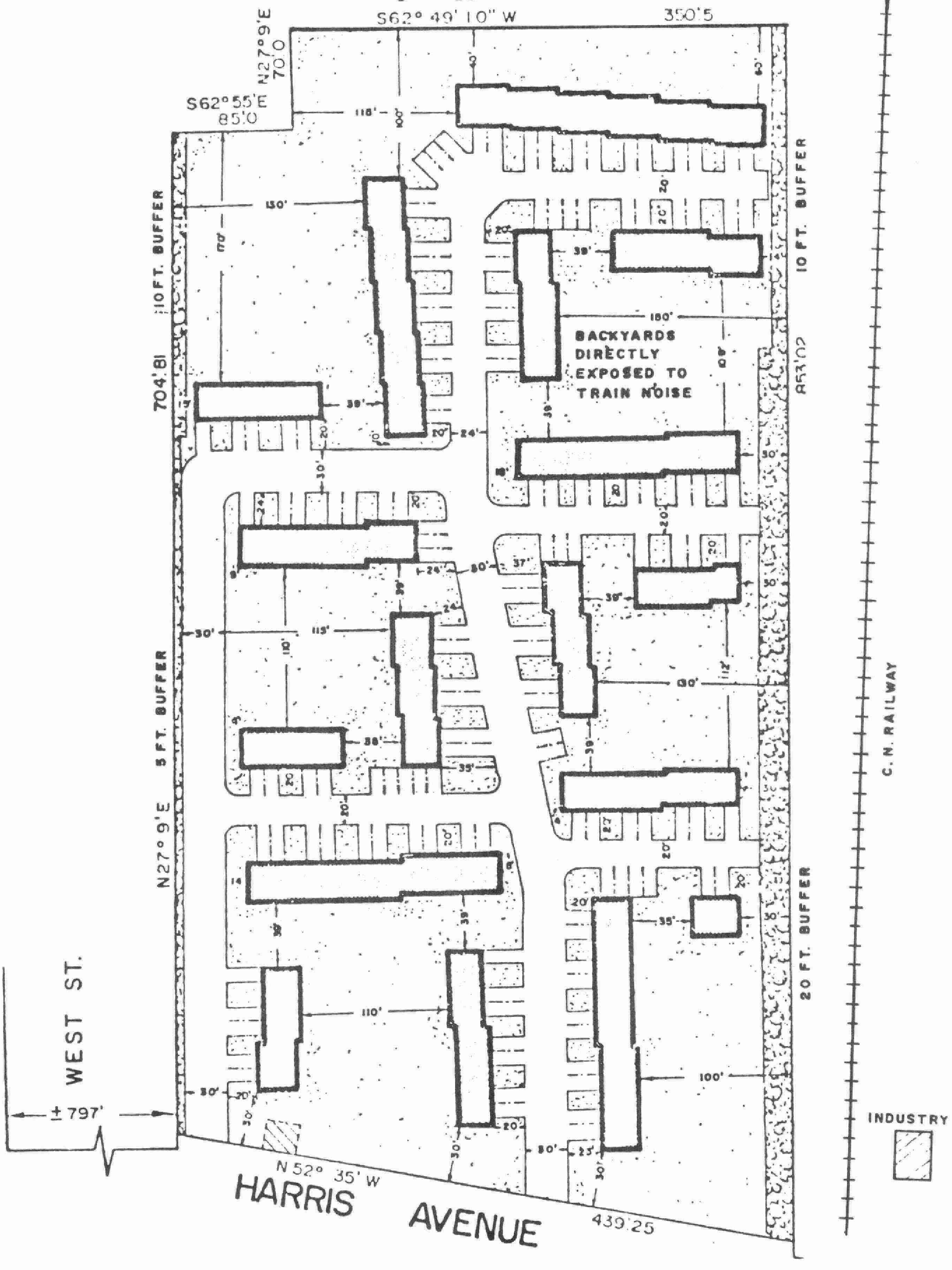


—Star photo by Doug Griffin

DOWNTOWN noise and pollution will be combated with sound barriers and other measures in St. Lawrence housing project. The city is building parkland housing for 10,000 people between Front Street and the Gardiner Expressway from the O'Keefe Centre to Parliament Street.

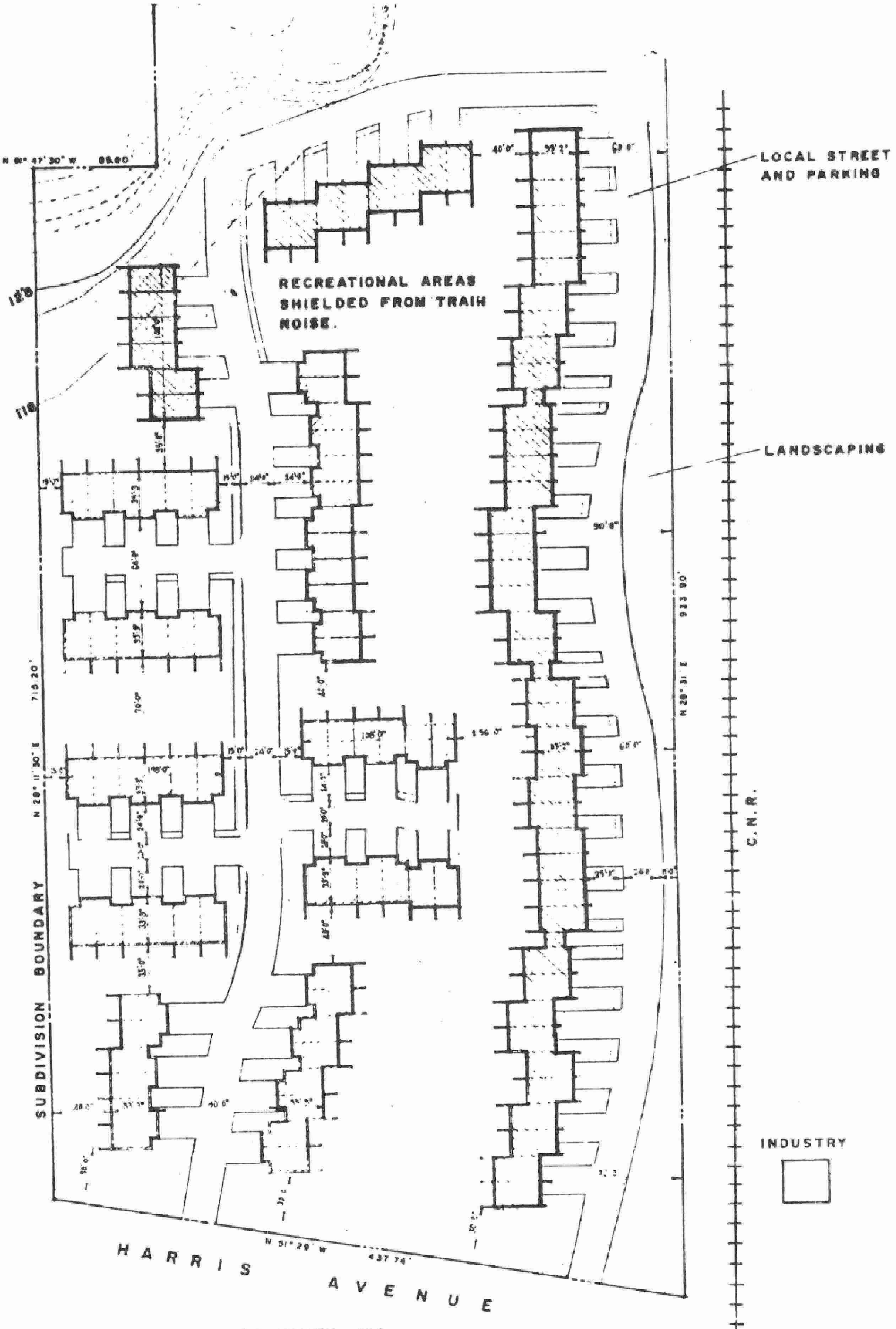
Figure 8.26. Noise control in Toronto's St.Lawrence housing project

as shown in Figure 8.27. Outdoor noise levels could not be complied with over the most part of the subdivision. The 3 m and 6 m buffer zones were virtually ineffective in providing any noise reduction. In Figure 8.28 the buffer zones were eliminated, and the townhouses were arranged in the form of a long and near continuous barrier block, running parallel to the train tracks. As a result the outdoor living areas for the entire subdivision were substantially shielded against train noise. It should be noted that the land yield has remained unchanged at 116 units after rearrangement and, in fact, the noise problem was solved without incurring any additional cost.



NO. OF TOWNHOUSE UNITS= 116

Figure 8.27. Inadequate noise control measures



NO. OF TOWNHOUSE UNITS = 116

Figure 8.28. Noise control measures incorporated

CHAPTER 9

SOUND ATTENUATION BY BARRIERS

1.0 INTRODUCTION

Noise barriers provide attenuation by shielding the receiver from the source of sound.

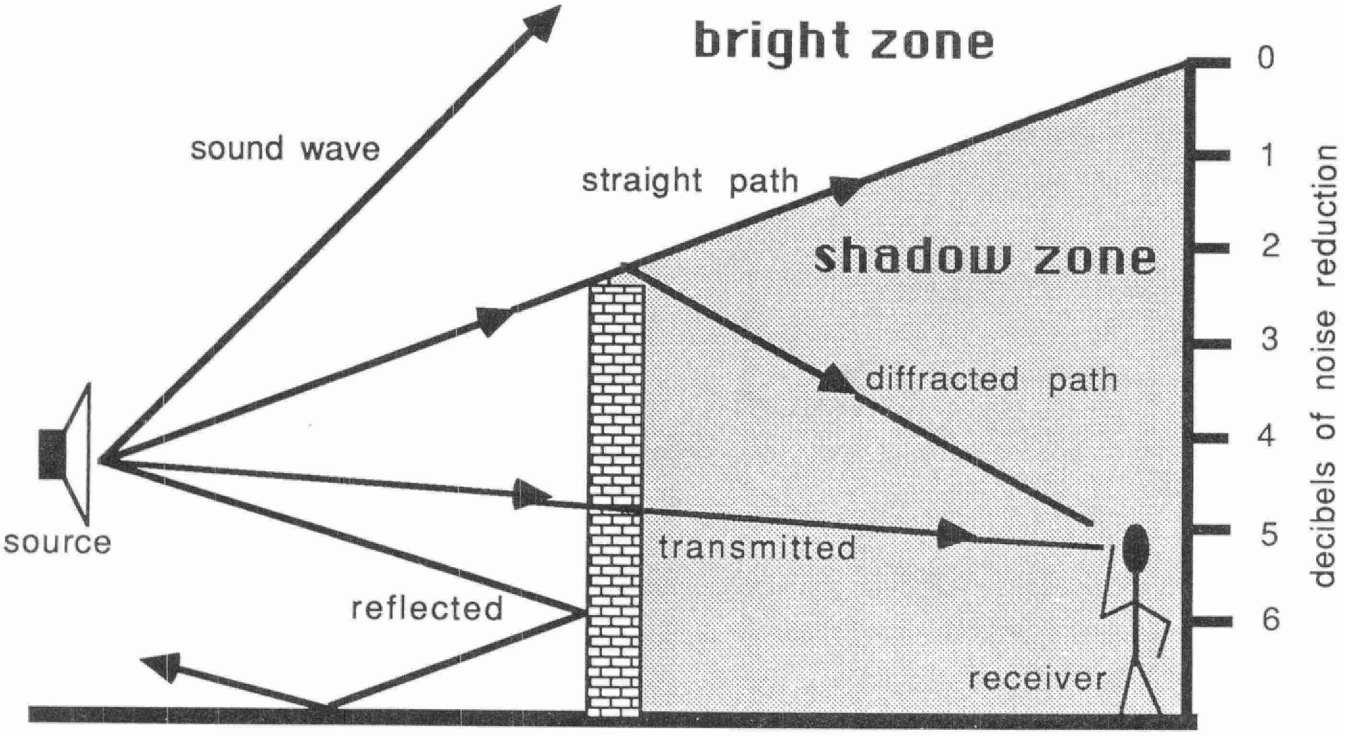


Figure 9.1. The effect of a barrier on sound waves

Figure 9.1 shows a progression of sound waves crossing a barrier (a wall, fence or similar construction). The sound waves near the top of the figure pass clearly over the barrier and are not affected by it. Sound waves which pass close to the barrier are diffracted by the barrier and hence bent round as shown in the figure. A receiver

standing in the region of the bent sound waves (shadow zone) will hear sound at a reduced level than a receiver standing in the area of the unaffected sound waves (bright zone). This process of sound wave diffraction is similar to the process of diffraction in the study of the behaviour of light.

2.0 PATH LENGTH DIFFERENCE AND FRESNEL NUMBER

From optical diffraction theory, the sound attenuation of an acoustical barrier is found by calculating the "path length difference" or the extra distance the sound is forced to travel because of the presence of the barrier.

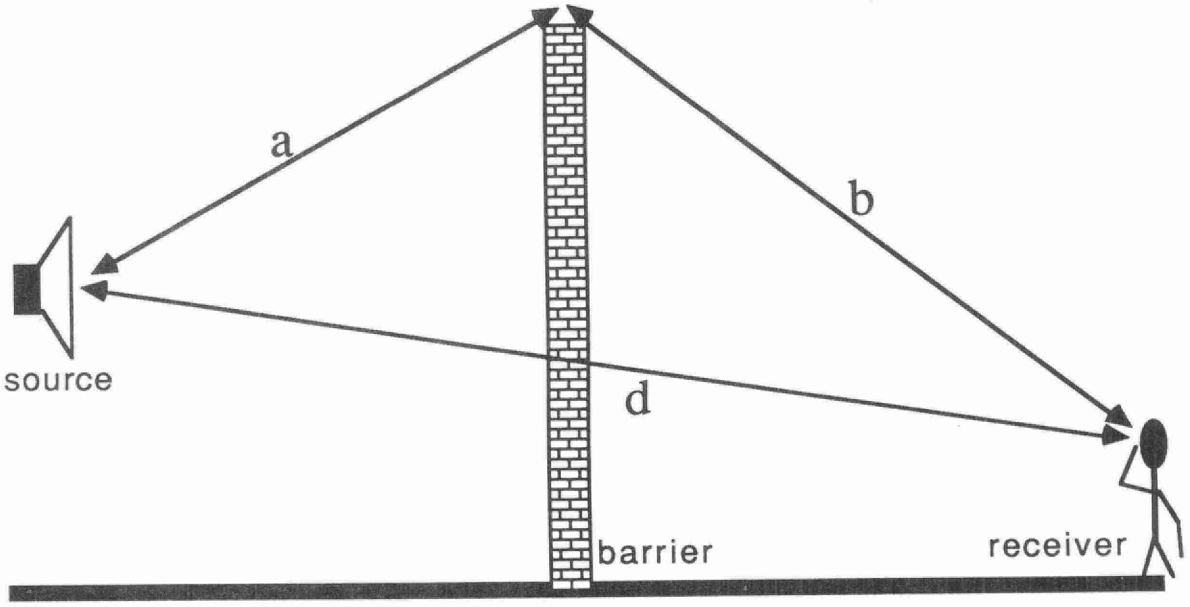


Figure 9.2. Definition of path length difference

2.1 Thin Barriers

Figure 9.2 shows a barrier placed between a source and a receiver. In the absence of the barrier, the sound travels directly between the source and the receiver, shown as the distance d. However, with the barrier in place, the sound must travel from the source to the top of the barrier (distance a) and from the top of the barrier to the receiver (distance b). So with the barrier in place the sound must travel through a total distance of a + b. Subtracting d from a + b gives the extra distance the sound must travel because of the barrier.

Figure 9.3 defines the appropriate parameters: the source barrier distance D_{SB}, the barrier receiver distance D_{BR}, the source height H_S, the barrier height H_B and the receiver height H_R.

The path length difference (PLD), δ, can then be calculated from:

$$\delta = a + b - d \qquad (9.1)$$

where $a = \sqrt{[H_B - H_S]^2 + [D_{SB}]^2}$

$b = \sqrt{[H_B - H_R]^2 + [D_{BR}]^2}$

and $d = \sqrt{[H_S - H_R]^2 + [D_{SB} + D_{BR}]^2}$

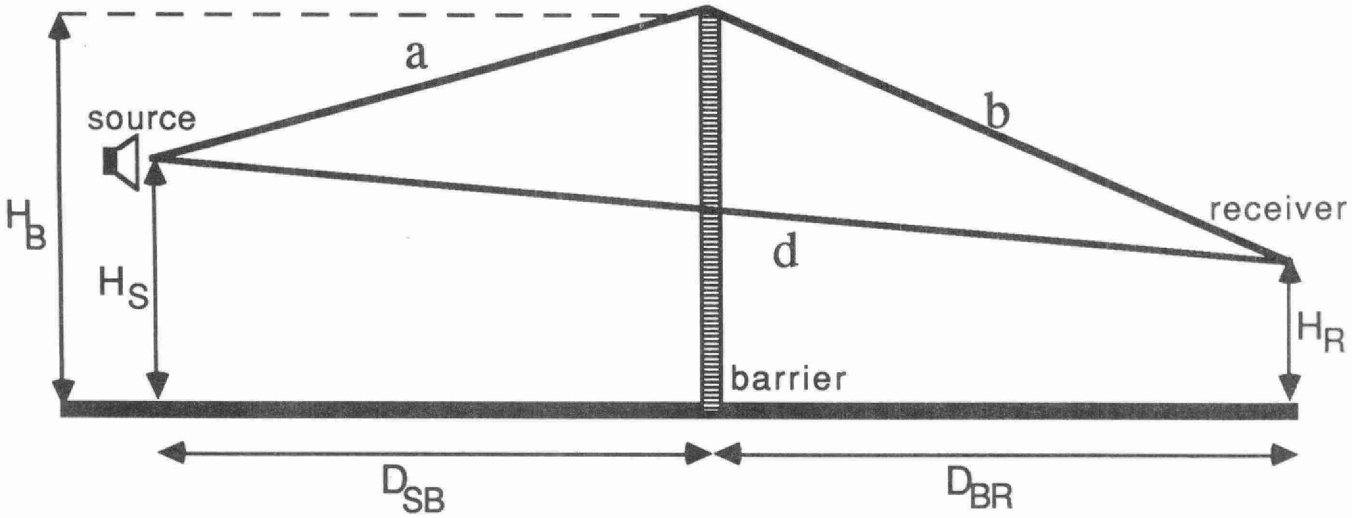


Figure 9.3. Calculation of PLD for a thin barrier

2.2 Thick Barriers

It is often possible to use a row of townhouses or even an apartment block as a noise barrier. In this case some extra sound reduction is achieved as the sound is diffracted around the two upper edges of the building (see Figure 9.4). Again the PLD can be used as a simple indicator of the sound reduction. If the building thickness is defined as T, then the calculation of PLD, δ, is as follows:

$$\delta = a + b + T - d \qquad (9.2)$$

where $a = \sqrt{(H_B - H_S)^2 + [D_{SB}]^2}$

$b = \sqrt{(H_B - H_R)^2 + [D_{BR} - T]^2}$

and $d = \sqrt{[H_S - H_R]^2 + [D_{SB} + D_{BR}]^2}$

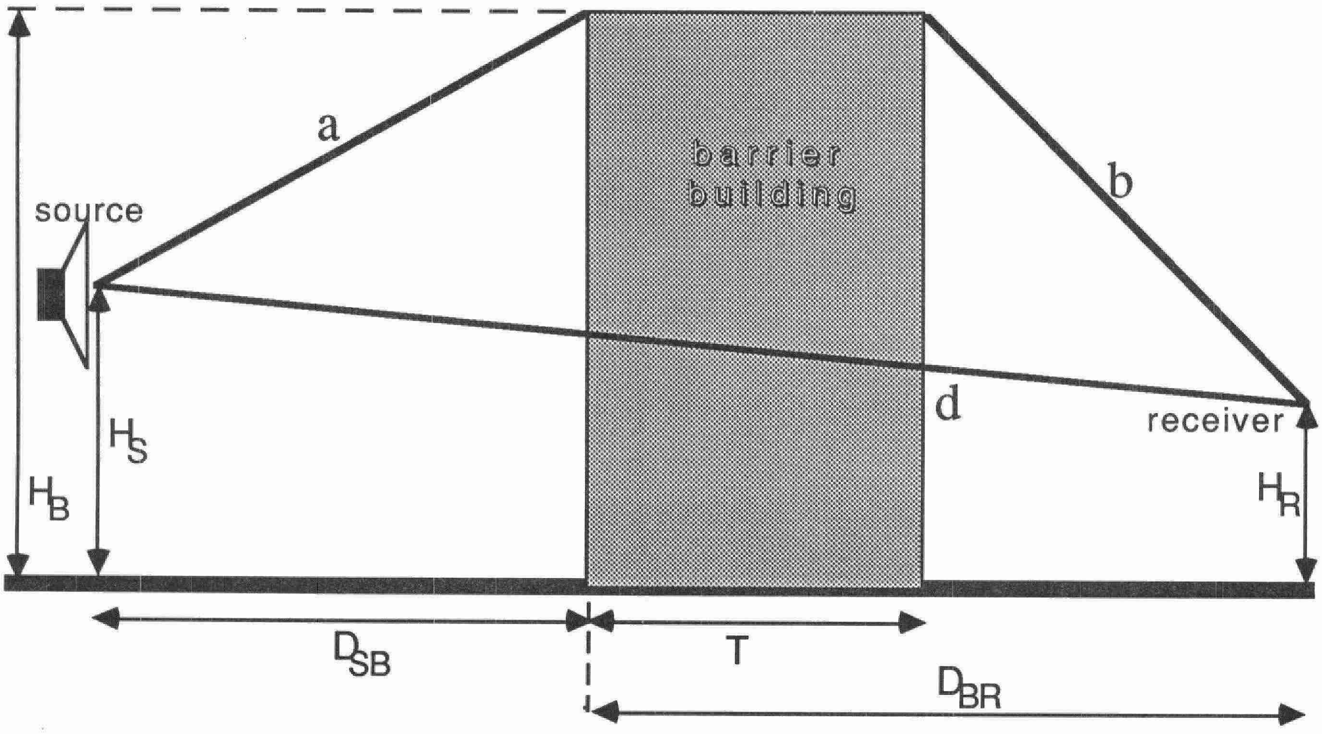


Figure 9.4. Calculation of PLD for a thick barrier

Care should be taken when calculating PLD that the receiver is in the shadow zone, that is, the source cannot be seen by the receiver. In this situation the PLD is given a positive sign and a significant sound attenuation will result. If, however, the source can be seen by the receiver despite the presence of the barrier, then the receiver is in the bright zone and the PLD should be given a negative sign. In the later case the barrier will give very little, or no, sound reduction at the receiver position.

2.3 Fresnel Number

Once the PLD has been calculated, the sound attenuation of the barrier can only be calculated with a knowledge of the wavelength or frequency of the sound wave under

consideration. This is necessary as low frequency sound (or long wavelength) can be diffracted or "bent" more easily than high frequency sound (or short wavelength). Following the optical diffraction theory, a "Fresnel Number" (N) must be calculated as follows before the sound attenuation can be found.

Fresnel Number $N = (2\delta/\lambda)$

where λ is the wavelength of the sound
and δ the PLD. (9.3)

As we usually work with frequency rather than wavelength, it is useful to convert the formula for N into a form involving frequency (f) rather than wavelength.

$$f = c/\lambda$$

where c is the speed of sound in air

Thus $\lambda = c/f$

and $N = (2f/c)\ (\delta)$ (9.4)

Care should be taken when using this equation to use a consistent set of dimensions. If the PLD is calculated in metres, then the speed of sound used must be in metres/second. If the PLD is calculated in feet, then the speed of sound must be in feet/second.

Thus $N = (2f/344)\ (\delta)$ (PLD in metres)
or $N = (2f/1130)\ (\delta)$ (PLD in feet) (9.5)

It is clear that in order to calculate N, either the frequency of the sound must be known, or if the sound covers a wide frequency range, some representative

frequency must be assumed. The Ministry of the Environment uses a frequency of 500 Hz to represent both the road transportation and the train transportation noise.

Knowledge of the representative frequency allows calculation of simple conversion factors from δ to N. The Fresnel number for a frequency of 500 Hz is:

$$\begin{aligned} N &= 2.9\,\delta \text{ (PLD in metres)} \\ &= 0.88\,\delta \text{ (PLD in feet)} \end{aligned} \qquad (9.6)$$

3.0 ATTENUATION FOR POINT AND LINE SOURCES

A noise barrier provides different values of sound attenuation for stationary point sources and line sources. Moving point sources, for which the attenuation for a passby is required, should be considered as line sources. In general, the attenuation for a line source is less than that for a point source.

The barrier attenuation for a point source, assuming an infinite barrier, Δ can be expressed as:

$$\Delta = 20 \log \left[\sqrt{2\pi N}/\tanh \sqrt{2\pi N}\right] + 5 \text{ dB}, \quad -0.19 < N \leq 5.03$$

$$= 20 \text{ dB}, \qquad N > 5.03$$

where $N = N_0 \cos \Phi$

N_0 is the Fresnel number, $N_0 = 2\delta/\lambda$ (9.7)

and Φ is the angle subtended by the line connecting the source and receiver and a line perpendicular to the barrier.

At a frequency of 500 Hz the above expression can be written as:

$$\Delta = 20 \log [\sqrt{19.3\,|\delta| \cos \Phi}/\tan \sqrt{19.3\,|\delta| \cos \Phi}] + 5 \text{ dB, for } -0.06< \delta <0 \text{ m}$$

$$= 20 \log [\sqrt{19.3\,|\delta| \cos \Phi}/\tanh \sqrt{19.3\,|\delta| \cos \Phi}] + 5 \text{ dB, for } 0< \delta <1.725 \text{ m}$$

$$= 20 \text{ dB, for } \delta >1.725 \text{ m} \qquad (9.8)$$

For a line source, the attenuation provided by an infinite barrier is obtained by integrating the above expression from $-\pi/2$ to $\pi/2$, and is given by:

$$\Delta_1 = 20 \log [1/\pi \int_{-\pi/2}^{\pi/2} 10^{-\Delta/10}\, d\Phi] \qquad (9.9)$$

where Δ is the point source attenuation, defined in Equation (9.7) or (9.8).

Figure 9.5 gives the attenuation provided by an infinite barrier for both a point and a line source.

The upper curve on Figure 9.5 applies to a point source such as a stationary machine, car or truck, or an idling locomotive. The lower curve applies to a line source such as a continuous flow of traffic along a roadway or the wheel-rail noise from a long freight train. It can be seen from the graph that the attentuation provided by a barrier is less for line sources than point sources.

The graphs in Figure 9.5 assume:

- That the barrier is very long (at least eight times the source to receiver distance) or is turned through

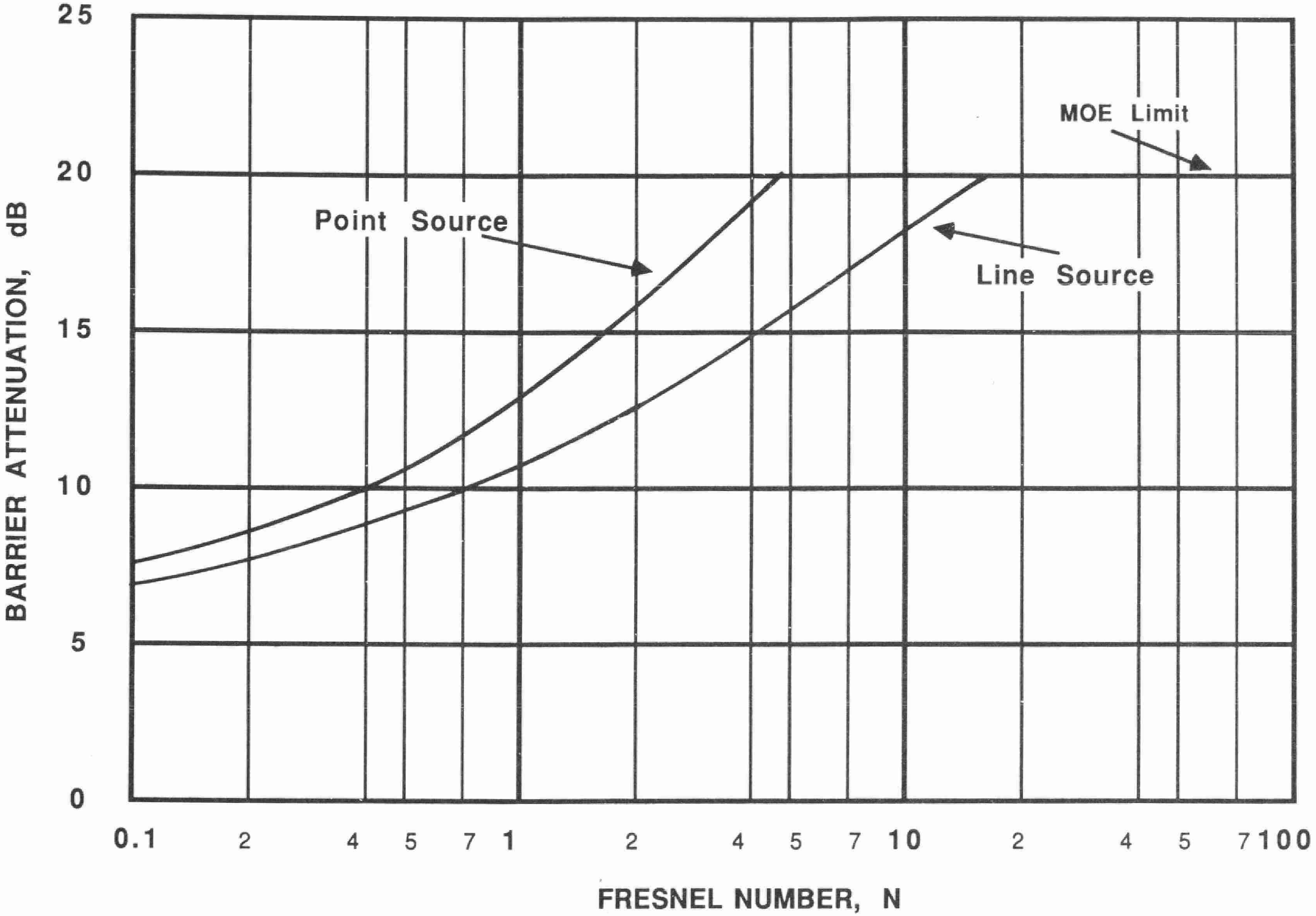


Figure 9.5 Barrier attenuation against Fresnel Number, N

a right angle away from the source at both ends to protect the receiver from the sides.

- That the barrier does not allow sound to penetrate through itself and thus raise sound levels in the shadow zone. To avoid this effect, the barrier can be made of any material (solid wood, masonry or earth in the form of a berm) so long as it has a surface mass density of 20 kg/m^2 (4 lbs/ft^2) and has no holes or gaps.

- That the barrier is at right angles to a line drawn from the receiver to the source (for a point source) or a line drawn from the receiver perpendicular to the source (for a line source).

In many practical cases, conditions described above in Section 3.0 are not met and the barrier cannot be considered infinite. Therefore, the attenuation provided by a finite barrier must be calculated. Finite barrier attenuation is obtained from Equation (9.9), replacing the angles $-\pi/2$ and $\pi/2$, (i.e. -90° and 90°) by appropriate values.

It was indicated earlier that in some instances, a barrier is extended or wrapped around a corner lot or a row of houses to simulate an infinite barrier. A simple example is shown in Figure 9.6. The barrier attenuation calculation depends on the angle subtended at the receiver by the barrier. For the receptor location shown in Figure 9.6, the wrap around section of the barrier can be represented by an equivalent barrier section which considerably extends the overall length of the barrier parallel to the roadway.

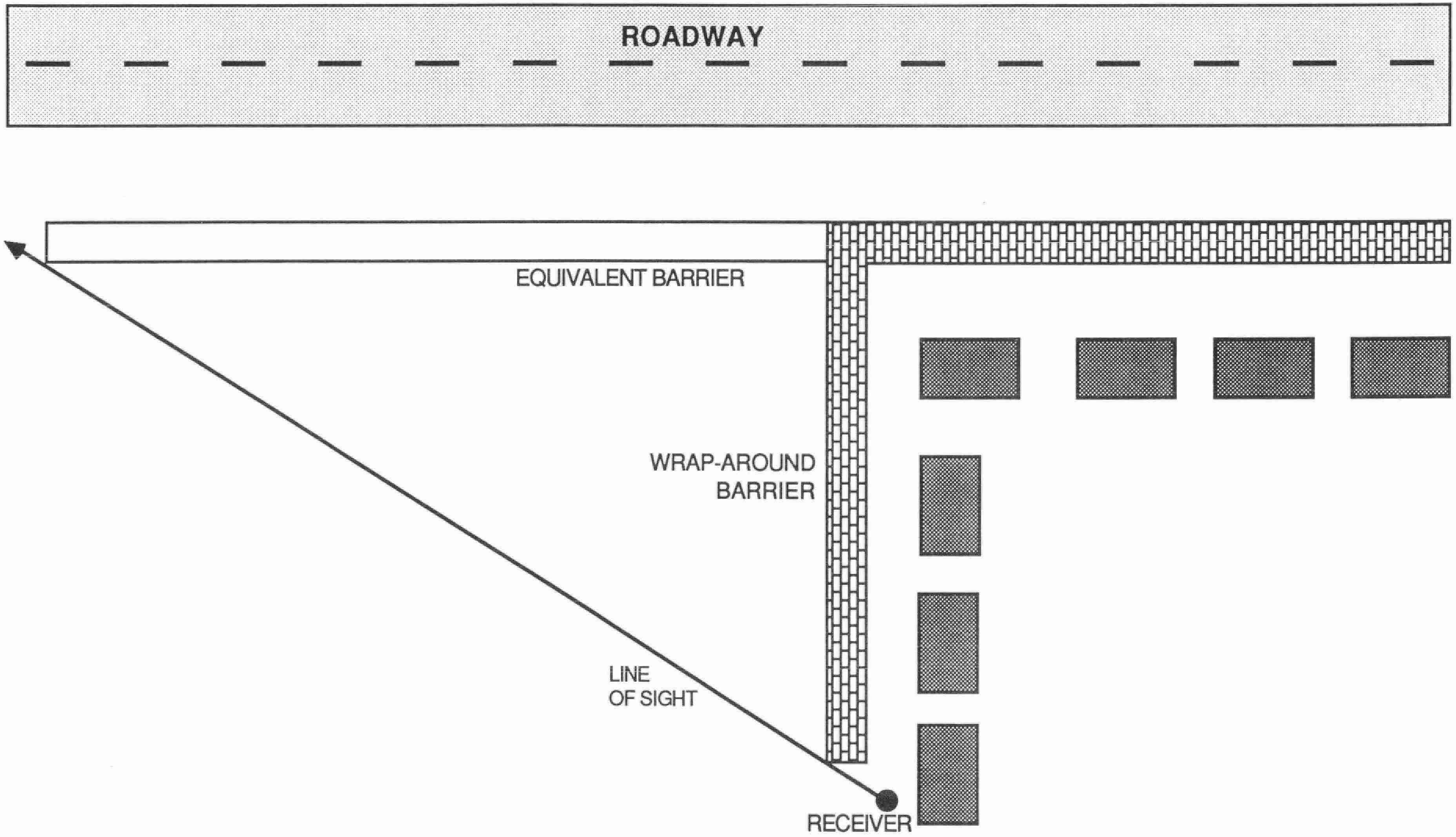


Figure 9.6. Equivalent configuration for wrap-around barriers

4.0 EFFECTIVE SOURCE HEIGHT AND GROUND ATTENUATION

Before a barrier attenuation can be calculated the source height must be known. For a highly complex source such as traffic noise, no single source height exists and so a single effective source height must be used. The choice of this effective source height may be affected by considerations of ground attenuation.

As a sound wave passes over a region of absorptive surface, the source sound level decreases by more than the expected 3 dBA per doubling of distance for a line source, or the 6 dBA per doubling of distance for a point source. This extra sound level decrease is known as ground attenuation. If, however, the sound wave has to travel over a barrier in order to reach the receiver, it must necessarily travel further away from the ground and hence resulting in a smaller ground attenuation.

The effect of interposing a barrier between a source and a receiver is thus two-fold. First, the sound level is increased because at least a part of the ground attenuation is removed and secondly, the sound level is decreased by the presence of the barrier and ensuing barrier sound attenuation. Thus, this removal of part of the ground attenuation makes the barrier less effective, a fact which must be taken into account when calculating the barrier attenuation.

Two noise prediction models, train and road traffic, recommended for use by this Ministry have been described in Chapter 7. As was discussed, train noise emanates from two main sources, the locomotive itself and the wheel-rail interaction. The locomotive noise propagates from both the exhaust stack on top of the locomotive at a height of

about 5 m above the track and from the engine casing which ranges from a height of about 2 m up to 5 m. As a reasonable compromise, the source height is assumed to be 4 m above the rail level.

The wheel-rail noise on the other hand radiates from the reverberant space between the ground and the car underside. Again as a reasonable compromise, the source height is assumed to be 0.5 m above the rail level.

The road traffic noise prediction method recommended for use by this Ministry is based on a model developed by the Federal Highways Administration in the United States. In the model, the source height is calculated based on the truck traffic percentage.

Details of the effect of ground attenuation and the effective height are given in Guidelines for Road and Railway Traffic Noise Assessment incorporated in Appendices A and B.

5.0 MINIMUM HEIGHT REQUIREMENT FOR BARRIERS

The equations presented in the previous sections predict a smooth decrease of barrier attenuation to '0 dB' by including negative PLD values, i.e. by including receiver positions in the bright zone. In certain situations, however, even small topographical variations may predict barrier attenuations of 3 to 4 dB where the receiver would be well in the bright zone.

To avoid such conditions where barrier attenuation predictions can be erroneously applied, the Ministry guidelines reuqire that if a barrier is used as a physical noise control measure, its height must be such that the barrier breaks the line of sight between the source and receiver.

CHAPTER 10

BUILDING ACOUSTICS

1.0 BASIC ELEMENTS OF NOISE CONTROL IN BUILDINGS

Successful control of indoor noise originating from outdoor sources depends on understanding the behaviour of the interaction between sound waves and the materials with which they come into contact.

Two main factors affecting this interaction are the transmission of sound energy through a material and the absorption of energy at, or in the vicinity of, the material's surface. One should be careful to distinguish one from the other since, in general, they are caused by different physical properties of the material.

A material that allows only a very small transmission of sound energy is not usually effective as an absorber of energy, and vice-versa.

1.1 Sound Transmission

When sound travelling through the air encounters a panel of a given material (such as a wall or window) the vibration of the air causes the panel to vibrate and some of the incident energy is reflected. The vibrating panel sets the air on its opposite side into vibration. As a result, the energy transmitted through the panel appears on the other side as a sound wave usually of reduced intensity.

1.2 Sound Absorption

The absorption of an incident sound wave occurs at, or near, the surface of the panel. When sound waves are incident upon the surface of a panel, air flows in and out of minute pores in the material due to the pressure changes produced by the sound. Resulting frictional forces convert the sound energy into heat although the actual amount of energy dissipated is very small. The total amount of incident sound energy reflected by the wall is thus reduced, lowering in turn the reflected sound level.

It is now possible to make a clear distinction between sound transmission and absorption. The former determines how much sound energy passes through the wall and enters the room. Once in the room, the energy is further reduced by the action of the absorbents (these may also be carpeting, furnishings, etc.) which determine the final sound level in the room resulting from the entering sound energy.

A term that describes the combined action of these two effects is "noise reduction", which is defined as the difference in sound level between the exterior and the interior of the building, regardless of the mechanism of the reduction.

2.0 SOUND TRANSMISSION LOSS AND STC RATING CONCEPT

2.1 Sound Transmission Loss

The measure of a material's ability to attenuate the passage of sound is the sound transmission loss. By

definition the Sound Transmission Loss, TL, is the ratio, expressed in dB, of the airborne sound power incident upon the panel to the sound power transmitted by the panel and radiated on the other side.

A panel having a high transmission loss would make a good insulator, a panel with a low transmission loss would be a poor insulator.

The Sound Transmission Loss of a panel is dependent on the frequency of the sound, the angle of incidence of the sound wave upon the panel and the mass and rigidity of the panel.

Analysis of the entire sound transmission loss frequency curve of a given panel provides the best method for evaluation of its sound insulating properties. Such a detailed procedure is usually not needed for many assessments in land use planning. A simpler method of rating partitions by a single number can be used.

This single number rating is a good means of comparing the performance of different panel constructions tested under identical (or nearly identical) conditions. The number is assigned by the testing laboratory according to a carefully defined procedure and is a fairly reliable measure of comparative acoustic performance between different panels. This number is called the Sound Transmission Class (STC) of the panel or material. The detailed procedure is given, for instance, in ASTM Standards E-90, E-336 and E-413. (See list of references.)

2.2 STC Rating Concept (Refer also to ASTM E-413)

To determine the STC of a test panel, the Sound Transmission Loss values, as determined in the 16

1/3 octave bands with centre frequencies in the range of 125-4000 Hz are compared with the values of STC reference contours as shown in Figure 10.1.

Comparison is made according to the following conditions:

A single unfavourable deviation (i.e. a value which falls below the contour) may not exceed 8 dB.

The sum of the unfavourable deviations shall not be greater than 32 dB.

Then the STC for the tested panel is the numerical value which corresponds to the Sound Transmission Loss value at 500 Hz of the highest contour for which the above conditions are fulfilled.

Figure 10.2 shows an example of determining the STC value for a 200 mm thick brick wall.

3.0 SOUND TRANSMISSION CHARACTERISTIC OF A MATERIAL

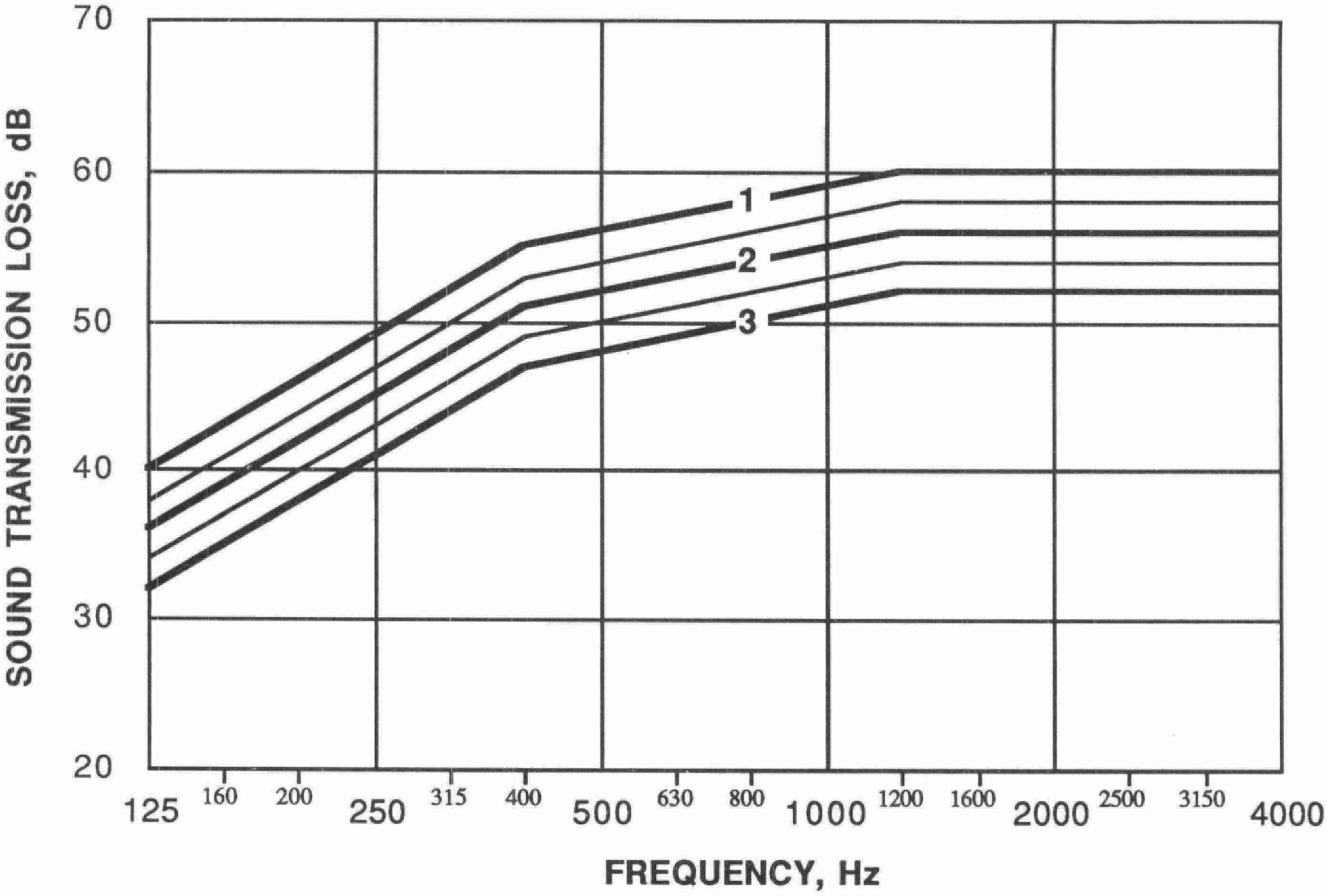
Several factors influence the sound transmission characteristic of a material; i.e. mass per unit area of the panel, its stiffness, frequency of incident sound and angle of incidence.

For a limp mass (i.e. material that lacked stiffness) the sound transmission is directly proportional to mass and frequency. Assuming random incidence of sound, the transmission loss of a panel can be expressed by:

$$TL = 20 \log (f.m) - 47$$

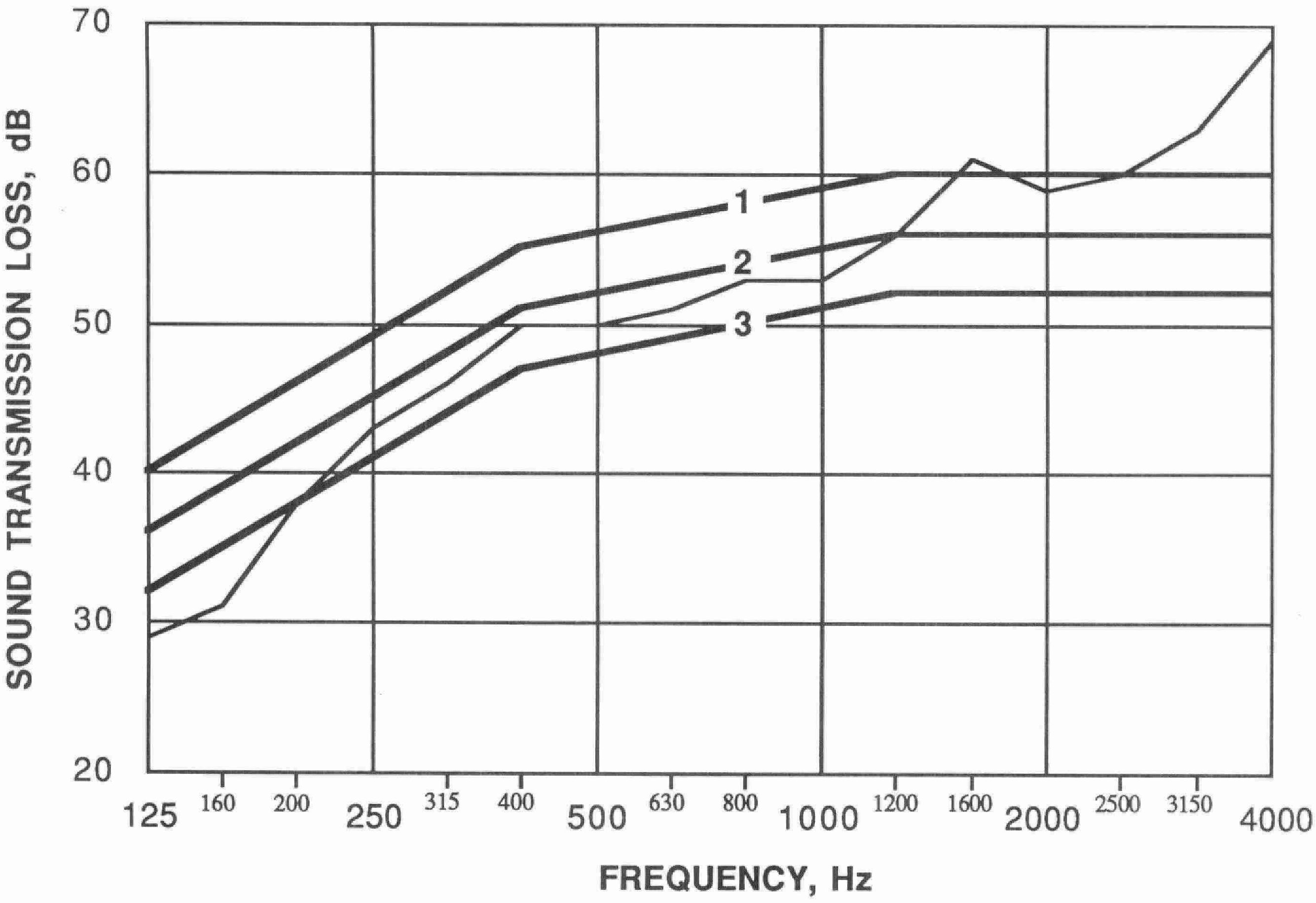
where f = the frequency in H_Z

m = surface mass density of a panel in kg/m^2 (10.1)



Contour 1 STC=56
Contour 2 STC=52
Contour 3 STC=48

Figure 10.1 Sound Transmission Class (STC) contours.



Contour 1 STC=56
Contour 2 STC=52
Contour 3 STC=48

——Transmission Loss Curve for 200 mm brick wall

Deviations in 16 - 1/3 Octave Bands from contour 2 (STC= 52)

125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000
7	8	4	2	2	1	2	2	1	2	0	-5	-3	-4	-7	-13

Individual unfavourable deviations < 8 dB,

Total unfavourable deviations < 32 dB.

Sound Transmission Class (STC) of the brick wall is 52

Figure 10.2 Determination of the STC value for a 200 mm Brick Wall.

From this equation it is easy to recognize that for a doubling of either the frequency or the mass the transmission loss will increase by 6 dB.

This is known as the "mass law". However, rarely does a panel act as a limp mass. Usually it moves in a more complex manner, depending upon its stiffness.

Figure 10.3 below show a typical sound insulation curve for a single panel.

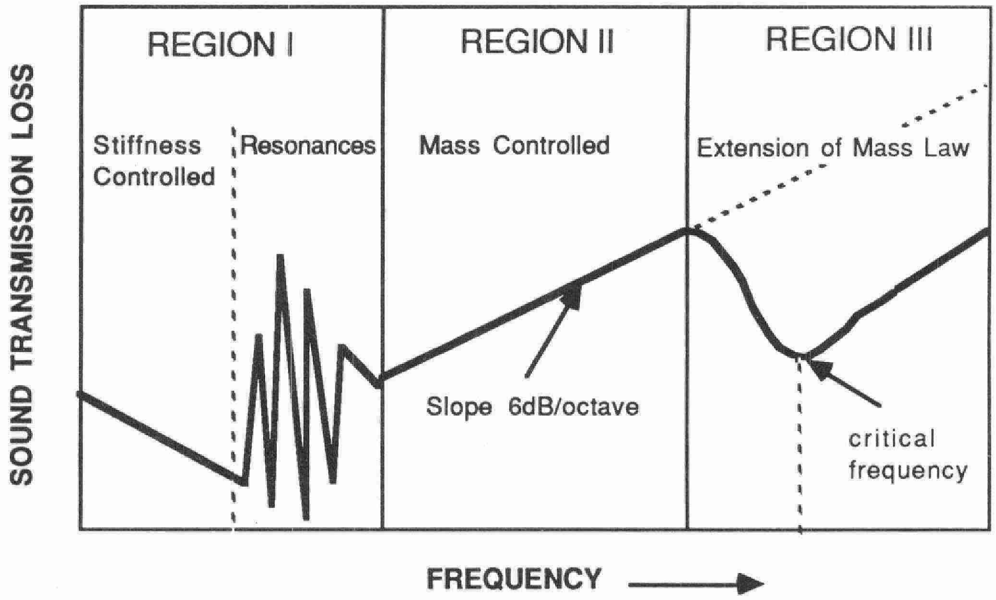


Figure 10.3 Typical sound insulation curve

The curve is broadly divided into three regions. In Region I (the low frequency range) the sound transmission of the panel is stiffness controlled at first and then fluctuates due to resonance effects. These resonance effects depend on panel size, mass, stiffness and on the method of fixing at the edges.

In most cases the size and material of the panel are such that the resonance frequency is well below the lowest frequency of interest.

In Region II the sound transmission is primarily mass controlled and the rate of increase, theoretically 6 dB per octave, is in practice about 4.5 dB per octave.

In Region III a marked drop in sound transmission loss may occur due to the so-called "coincidence effect" which occurs when the bending wave in a panel is in phase with an oblique wave front of the incident sound. This happens at some frequencies and at some angles of incidence with nearly all materials.

The lowest frequency corresponding to grazing incidence, at which the coincidence effect occurs is called the critical frequency.

In general, the coincidence effect may affect sound transmission loss of a panel more seriously than resonance (occurring in Region I) because it can occur well within the 100 Hz - 4000 Hz range.

4.0 SOUND TRANSMISSION PROCESS THROUGH COMPOSITE STRUCTURES

In the general case of panel application as a sound barrier, the panel may be a wall with a door and windows and may even be built in several sections each with a different transmission loss because of different construction.

The sound transmission loss of such a composite structure depends on the relative areas and transmission losses of its components.

4.1 Sound Transmission Coefficient

To find the average transmission loss of the entire assembly, an average transmission coefficient, t_S, has to be first determined. The sound transmission loss and sound transmission coefficient are related in the following manner:

$$TL = 10 \log (1/t_S) \qquad (10.2)$$

The amount of sound power passing through a building panel component is proportional to the product of the area and sound transmission coefficient.

4.2 Transmission Loss of a Component

The following can be shown for a multi-component wall system:

$$t_S.S = t_1.S_2 + t_2.S_2 + t_3.S_3 + \ldots\ldots$$

where S = total area of the wall

t_S = effective sound transmission co-efficient of the whole wall

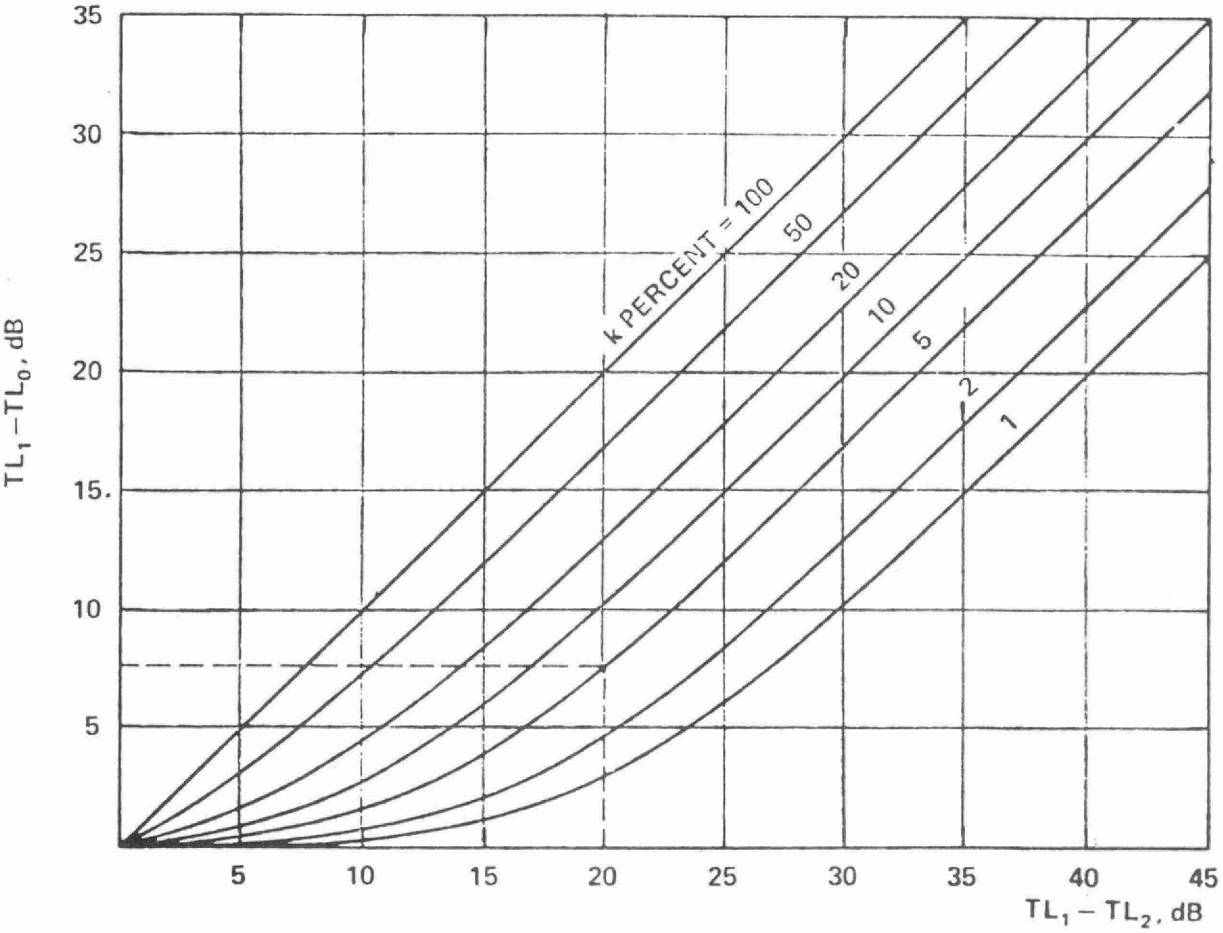
$t_1, t_2, t_3 \ldots$ = sound transmission co-efficients of the components

$S_1, S_2, S_3 \ldots$ = areas of the respective components

Then $t_S = (t_1S_1 + t_2S_2 + t_3S_3 + \ldots)/S$

and $TL = 10 \log (1/t_S)$ (10.3)

A graph for the rapid calculation of the composite insulation of a wall made up of two areas is shown on Figure 10.4.



TL$_0$ = sound transmission loss of combination wall

TL$_1$ = sound transmission loss of plain wall alone

TL$_2$ = sound transmission loss of window/door alone

k = percentage of wall area occupied by window/door

Example of use:

Transmission loss of wall, TL$_1$ = 50 dB

Transmission loss of window, TL$_2$ = 30 dB ∴ TL$_1$ - TL$_2$ =20 dB

If, area window/wall k = 5 %

then, from graph TL$_1$ - TL$_0$ = 8 dB

Transmission loss of Combination TL$_0$ = 50 - 8 dB

= 42 dB

Figure 10.4. The effective transmission loss of a composite wall

Thus, the importance of each element is determined by its individual sound transmission loss (attenuation) together with the surface area which it occupies in the room. Therefore, the main concern in the majority of houses are the windows, not only because they occupy a large surface area, but also because they themselves can have such low sound transmission loss values.

While the curves in Figure 10.4 can be used only for a wall with not more than two different TL section, a composite wall with more than two elements can be treated taking an additional section at a time as long as one remembers to use the previous composite TL at each step.

4.3 Effect of Gap Upon TL

Figure 10.4 may also be used to estimate the effect of gaps, cracks and openings on the transmission loss of doors, windows, etc. In this case, if the total area of the opening is known, the opening can be considered as the weak component with a sound transmission loss of zero dB.

It can be seen that it does not take a very large opening to reduce the sound transmission by a significant amount, especially for high sound transmission losses of the given component.

Suppose, for example, that a crack is left in a wall; the area of the crack constituting 1.0% of wall area. If the wall had been built with TL of 45 dB, the crack will reduce the TL by 25 dB to 20 dB.

5.0 STC RATINGS

5.1 Walls

Different wall materials and designs vary greatly in their sound insulating properties. Figure 10.5 shows a sample of wall types ranging from the lowest to the highest sound insulation values.

Figure 10.6 provides a visual summary of some ways in which the acoustical properties can be improved.

5.1.1 Effect of Increased Mass and Stiffness of the Wall

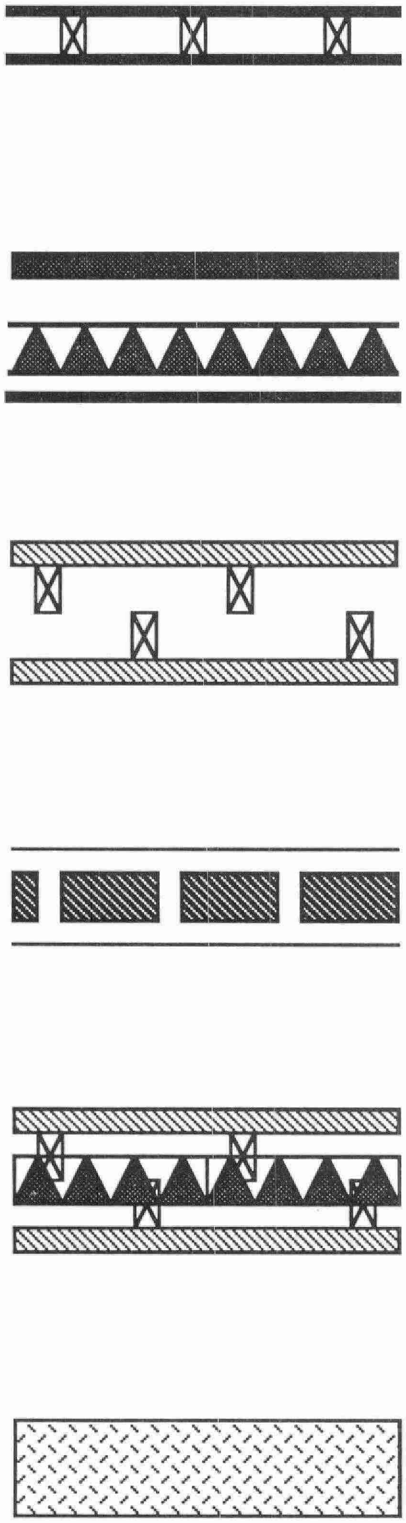
In general, the denser the wall material the more it will reduce noise. Thus, concrete walls are better insulators than wood walls of equal thickness. Increasing the thickness of a wall is another way to increase mass and improve sound insulation.

Doubling the thickness of a wall can result in as much as 6 dB reduction in noise level. However, the costs of construction tend to limit the feasibility of large increases in wall mass.

The relative stiffness of the wall material can influence its sound attenuation value. Care must be taken to avoid wall construction that can vibrate excessively at audible frequencies and transmit exterior sound to the indoor areas.

5.1.2 Use of Cavity Walls

A cavity wall is composed of two or more layers separated by an airspace. The airspace makes a more effective



Common stud wall
STC = 35

Typical wood siding
exterior wall
STC = 38

Staggered stud wall
STC = 39

4" brick wall

STC = 40

Staggered stud wall
with absorbent blanket
STC = 43

7" concrete wall
STC = 52

Figure 10.5. STC of common wall materials and constructions

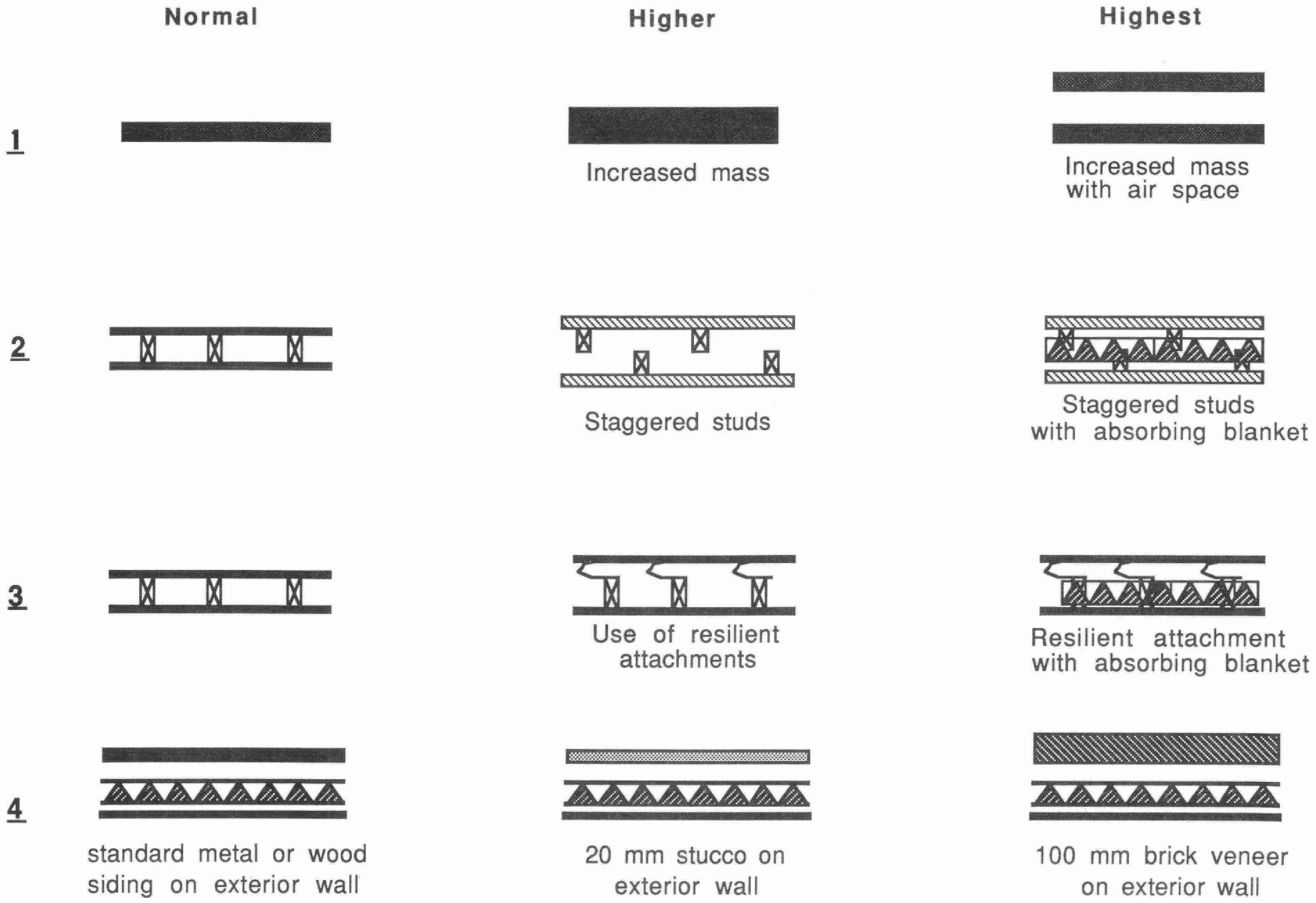


Figure 10.6. Improvement in wall sound insulation properties

sound insulator than a single wall of equal weight, thus leading to cost savings.

If two single layers of brick, for example, were used to make two walls weighing 250 kg/m² and 500 kg/m², the transmission loss curves would look like the lines 1 and 2 shown on Figure 10.7.

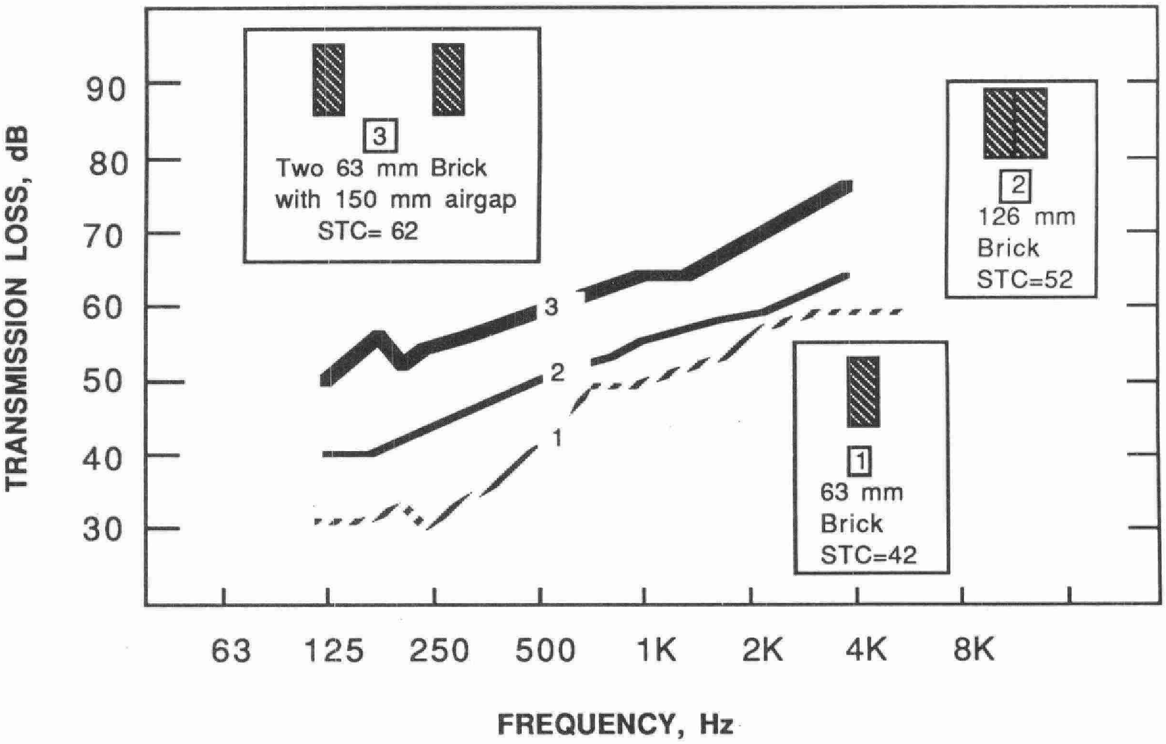


Figure 10.7 The effect of an air gap on TL of a wall

If the wall weighing 500 kg/m² was divided into two completely separate, air tight layers spaced about 150 mm apart, the transmission loss curve would look quite different, with dips caused by "resonance" of the assembly at several frequencies, as shown by the double wall curve 3 in Figure 10.7. The result would be that the average TL value would be significantly higher.

Increasing the width of the air space results in higher sound insulation values for a given wall. A 76 mm air space provides significant noise reduction, but increasing the spacing to 152 mm may reduce noise levels by an additional 5 dB or so. However, extremely wide continuous air spaces are difficult to design into walls, and the ultimate reduction potential is limited.

5.1.3 Increased Spacing Between Studs - Use of Staggered Studs

Double walls of wood or metal section frame construction may include split or staggered studs. In such construction the air, by virtue of its compressability, acts as the spring element or vibration isolator. A wider air space provides a softer spring action which results in greater sound insulation.

Also, the increased spacing between studs reduces excessive coupling between the two walls and results in a reduction of acoustic energy transmitted through such a structure. For example, in a common stud wall construction, a 61 cm stud spacing gives a 2 to 5 dB increase in STC over the common 41 cm spacing. Sound transmission loss can be increased further by attaching each stud to only one panel and alternating between the two panels. See Figure 10.6.

5.1.4 Use of Resilient Materials - Use of Dissimilar Leaves

Any rigid coupling between two walls of double leaf construction will lower its ability to reduce the amount of the transmitted energy. Panels made up of resilient layers such as fiber board, glass fiber board, resilient clips as well as semi-resilient attachments are simple to

insert and are relatively inexpensive. Their use can raise the STC rating of the assembly by 2 to 5 dB.

If the leaves are made of different materials and/or thicknesses, the sound reduction qualities of the wall are also improved.

5.1.5 Use of Sound Absorbent Liners

Also known as insulation blankets, these can increase sound attenuation when placed in the air space of a double wall. Sound absorbent liners tend to minimize the sound energy build-up in the hollow reverberant wall cavities, particularly at the higher frequencies, as well as minimize the effect of leaks.

Made from sound absorbing materials, such as mineral or rock wool, fibreglass, hair felt or wood fibres, sound absorbent liners can improve wall performance by as much as 10 dB.

They are effective in relatively lightweight frame construction and in heavy masonry construction if the structural transmission is not excessive. However, the use of insulation blankets in airspaces of common stud walls contribute little toward improved sound insulation. Owing to the rigid ties of the stud framing to the wall surfaces, the entire wall behaves like a diaphragm under vibration excitation and transmits the sound readily; thus the effectiveness of the insulation blanket is "short circuited".

Sound absorbent liners are also heat energy insulators and their use should be encouraged wherever possible as a conservation measure.

5.1.6 Proper Sealing and Installation of Walls

If the sound insulation of a high performance wall is to be realized, the wall must be of "air tight" construction and well sealed at the perimeter. Care must be exercised to seal all openings, gaps, holes, joints and penetration of piping. Even hairline cracks which might occur, particularly at the adjoining wall, floor and ceiling edges, during the drying out period or building settlement should be re-sealed. See Figure 10.8 below.

Figure 10.8. Example of good edge sealing practice

A substantially greater amount of sound energy is transmitted through a crack than would be normally expected on the basis of its area as illustrated in Section 4.3.

Also, proper installation of the wall requires that one should try to keep coupling or rigid ties to other structural assemblies at an absolute minimum. The purposes of decoupling the wall is to break up, or minimize, the sound flanking paths transmitted through the structure from outside or from one room to another.

5.2 Windows

Sound enters a building through its acoustically weak points and windows are one of the weakest parts of the wall. An open or weak window will severely negate the effect of acoustically very strong walls.

For example, if a wall with an STC rating of 45 contains a window with an STC rating 26 covering only 20% of its area, the overall STC of the composite wall will be STC 33, a reduction of 12 dB (check with Figure 10.4).

The following techniques can be used to reduce noise admitted through windows.

5.2.1 Closed Windows

The first step in reducing unwanted sound is to close and seal the windows. The greatest amount of sound insulation can be achieved if windows are permanently sealed. However, openable acoustical windows have been developed which are fairly effective in reducing indoor noise levels.

Whether or not the sealing is permanent, closed windows necessitate the installation of an air ventilation or air conditioning system. If a window must be openable, special seals are available which will allow the window to be opened.

5.2.2 Reduced Window Size

The smaller the window, the greater the net sound transmission loss of the total wall area of which the window

is a part. Reducing the window size is a technique used because it precludes the cost of expensive acoustical windows.

However, this technique is not very effective in reducing noise; e.g., reducing the proportion of window to wall size from 50% to 20% reduces noise inside by only 3 dB.

Table 10.1 illustrates STC ratings for a composite wall with various percentages of glass area.

Window Type	Single Glazing		Double Glazing		Special Construction Permanently Sealed	
Window STC	25		30		40	
Wall STC	35	50	35	50	35	50
% Glass area						
0	35	50	35	50	35	50
10	32	35	34	40	35	47
25	30	31	33	36	36	44
50	28	28	32	33	37	42
75	26	26	31	31	38	41
100	25	25	30	30	40	40

Table 10.1. STC values for a composite wall with various percentages of glass area

It should be mentioned that the Ontario Building Code requires a certain minimum window-to-wall size ratio. Ontario Building Code requires that windows of bedrooms,

living rooms and dining rooms must have a glass area which is at least 10% of floor area.

5.2.3 Increased Glass Thickness

Improved sound insulation can be obtained by increasing the weight (i.e. thickness) of the glass since glass reduces noise by the mass law principle.

Figure 10.9 shows the variation of mean sound insulation value with glass thickness for sealed windows, tested in the frequency range from 100 Hz to 3200 Hz.

It can be seen from the graph, that a 12.7 mm (1/2") thick glass has a maximum STC rating of 37 compared to an STC rating of 30 for ordinary 4.8 mm thick glass.

However, increase of glass thicknesses are only practical up to a certain point, when STC increases become too insignificant to justify the cost. For example, a 12.7 mm thick glass can have an STC of 37; increasing the thickness by about 50% to 19 mm only raises the STC by two points to 39.

A double glass pane acoustical window consisting of two 32 oz. glass panes (3.4 mm) separated by a 1.2 mm air space will have an STC of up to 39 depending on the type of sealant, frame construction, etc. A considerable improvement of window insulation can be achieved by laminating a single pane with a thick transparent plastic, which is both noise and shatter resistant. Laminated "sound-retarding" glass is a sophisticated form of safety glass, employing multiple layers of thin glass, laminated with thick, soft layers of plastic to make a monolithic pane, ranging in thickness from just over 6.4 mm to well

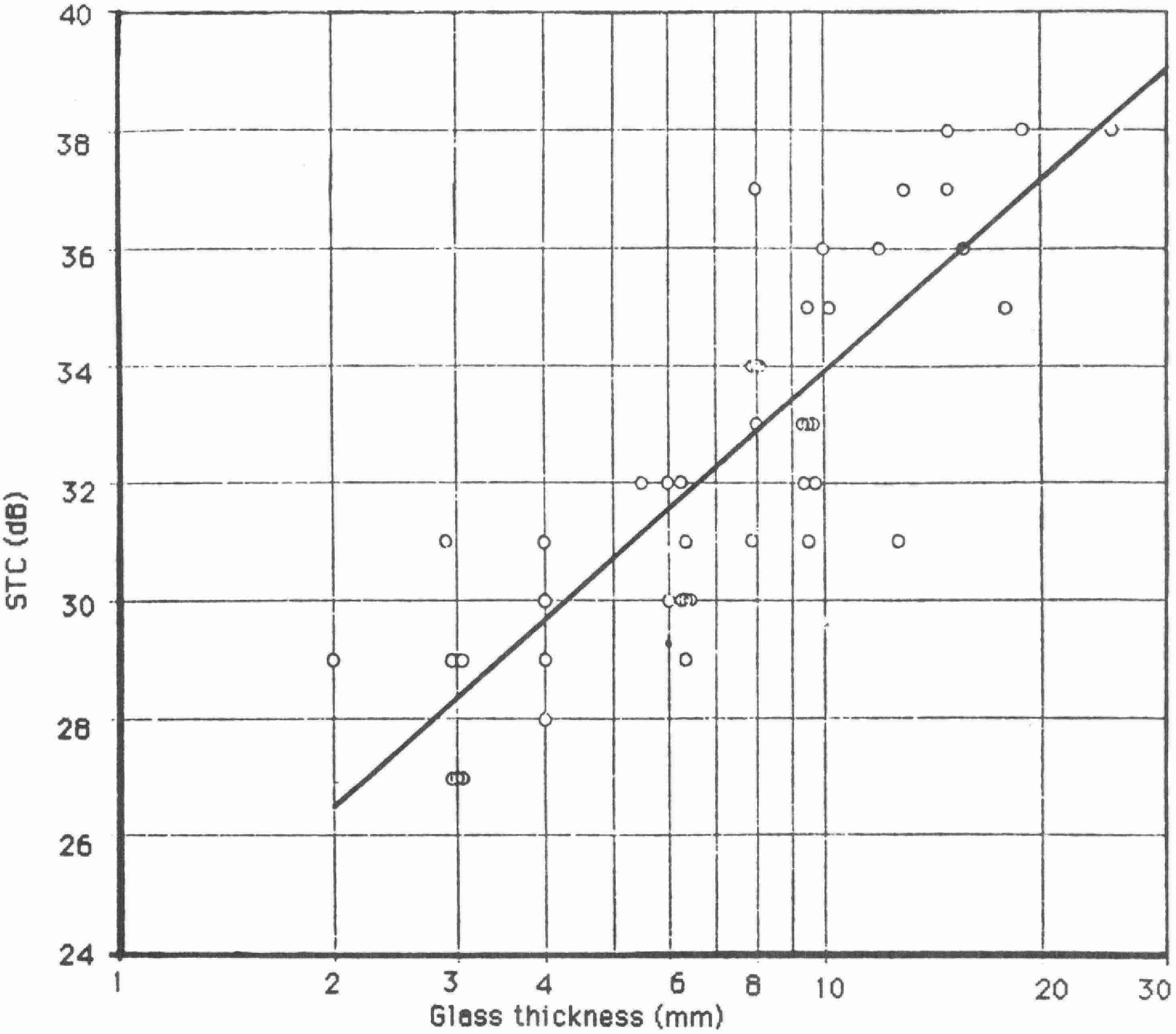


Figure 10.9. Increase of STC with thickness for glass

over 26 mm. The latter 26 mm composite thickness may well have an STC 40 rating.

5.2.4 Double Glazed Windows

Double glazed windows are paired panes, separated by an air space, hung in a special frame. Generally, the performance of the double glazed window may be increased with:

- increased air space width
- increased glass thickness
- proper use of sealings
- slightly dissimilar thickness of the panes
- slightly non-parallel panes

Sound insulation generally increases with increased gap between the glass panes. However, experimental studies of double glazed units have shown that sound insulation approaches a maximum with an optimum spacing of 100 mm and only a small increase occurs thereafter with greater air spacing.

In all double and multiple glazing systems, lining the sides of the air space with sound-absorbent materials reduces the resonances within the cavity, resulting in a worthwhile improvement in sound insulation. The increase in insulation will depend on the dimensions of the air space and the properties of the absorbent material.

It is also important that the panes of a double glazed window be mechanically isolated from each other. Where the panes are fixed in separate frames, the frames should be so mounted that vibrations from one cannot be easily transmitted to the other.

As in the case of all windows, proper sealing is extremely important. To achieve an STC above 43, double glazed windows should be sealed permanently. If the windows must be openable, there are special frames and sealings available which allow a maximum STC of 43.

To further improve the sound insulation between double glazed panes, the panes could be of different thicknesses, different weights and slightly non-parallel to each other. The non-parallel panes is expected to prevent acoustical coupling and minimize resonance effects. Figure 10.10 shows examples of windows with panes of different thickness and with non-parallel panes.

The construction of such glazing systems is usually expensive and, recent studies have shown that slanted windows do not improve the STC over a non-slanted double glazing (See Reference list).

5.2.5 Practical Window Insulation Values

Because of differences in constructional detail, fixing variations in the window size and room absorption, it is not possible to give general insulation figures which are valid for all cases.

Table 10.2 shows the practical insulation values that can be expected from various types of windows. They are mean values, each representing a possible range of 6 dB (3 dB) and can be used to give reasonably accurate results provided that the window is, at least, about 2 m^2 in area and forms part of a room of normal size with ordinary furnishings.

Most values in the table are based on measured data. Glazing systems for which no measured values were avail-

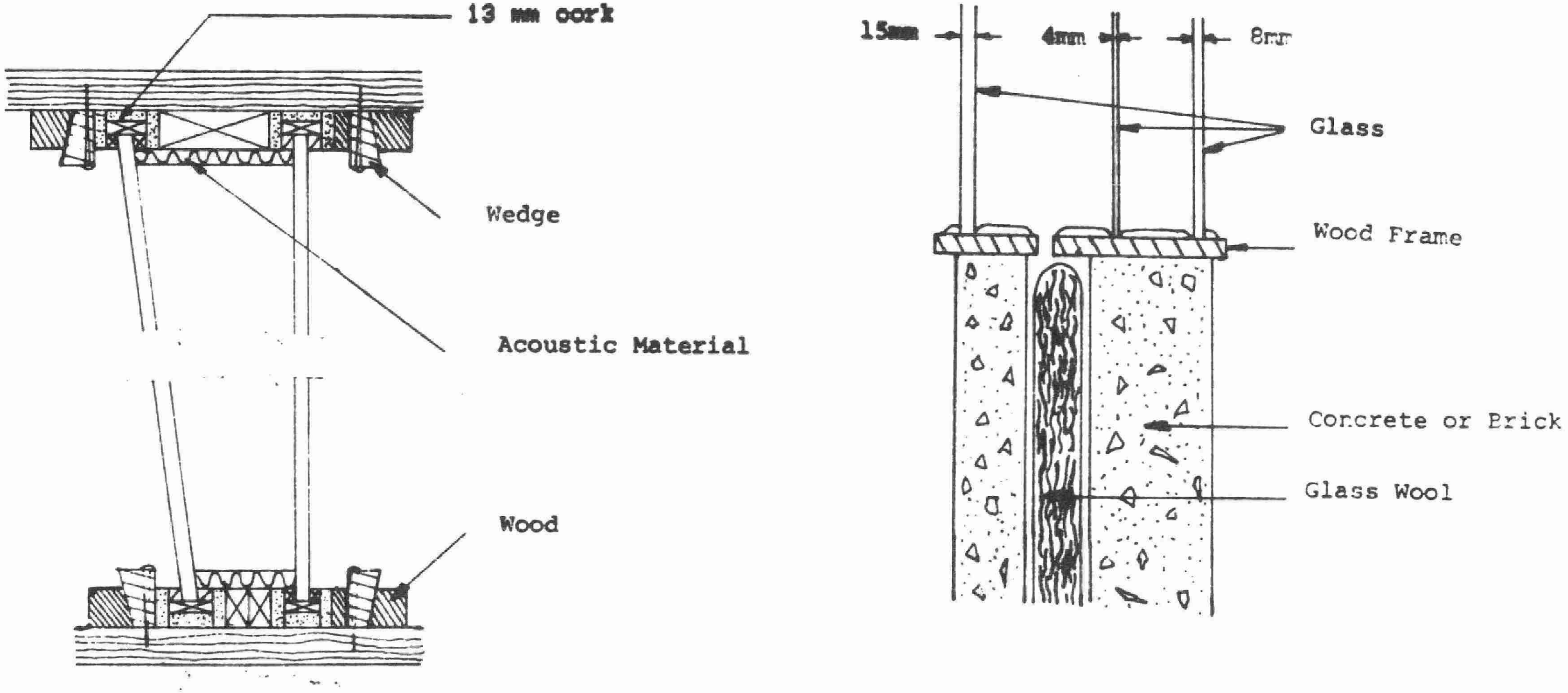


Figure 10.10. Sound retardant windows of special design

Window Type	Field Insulation
Normal opening lights, single glazing, (closed)	*estimated values
3 mm to 6 mm glass	*21
13 mm glass	*30
Sealed or fixed single glazing	
3 mm glass	29
4 mm glass	30
5 mm glass	*31
6 mm glass	32
10 mm glass	*34
13 mm glass	*35
20 mm glass	36
26 mm glass	37
Normal opening lights, double glazing, (closed)	
3mm - 4 mm glass with 100 mm air space without absorbent between panes	*35
3mm - 4 mm glass with 100 mm air space with absorbent between panes	*39
6mm glass with 100 mm air space with absorbent between panes	*41
Sealed or fixed double glazing	
3mm glass with less than 50 mm air space without absorbent	32
4mm glass with less than 50 mm air space without absorbent	34
4mm glass with less than 50 mm air space with absorbent	*35
4mm glass with 50mm air space without absorbent	41
4mm glass with 50mm air space with absorbent	*43
4mm glass with 100mm air space without absorbent	*43
4mm glass with 100mm air space with absorbent	44

continued on next page

Table10.2. STC ratings for various windows

Window Type	Field Insulation
	*estimated values
6 mm glass with less than 50 mm air space without absorbent	*36
6 mm glass with less than 50 mm air space with absorbent	*37
6 mm glass with 50 mm air space without absorbent	*42
6 mm glass with 50 mm air space with absorbent	*43
6 mm glass with 100 mm air space without absorbent	*44
6 mm glass with 100 mm air space with absorbent	46
<u>Laminated single glazing, sealed or fixed</u>	
6 mm laminated glass	*35
7 mm laminated glass	36
12 mm laminated glass	38
16 mm laminated glass	41
20 mm laminated glass	43
<u>Thermopanes (double glazing, sealed and fixed)</u>	
3 mm glass with 6 mm airspace	30
3 mm glass with 13 mm airspace	31
4 mm glass with 13 mm airspace	31
6 mm glass with 13 mm airspace	35

Table 10.2. Concluded.

able are given values obtained by interpolation or estimation and these are marked in the table by asterisks.

5.3 Doors

The transmission loss of doors obeys the same mass law that holds true for single panels. Generally the greater their density the better their sound insulating properties.

However, a good acoustical seal around the edges and insulation in the cavity of a double leaf door are both essential. Improper sealing around the edges of even thick doors will result in poor sound insulation and, therefore, care should be taken that a good positive seal exists between the door frame and the door panel.

The table below gives the STC rating of typical designs of exterior doors, separately for closed and for sealed conditions.

Type of Door	Closed	Sealed
Wood, solid core 46 mm, 20 kg/m^2	30	35
Same wood, solid core with aluminum storm door	34	42
Wood, hollow core 46 mm, 6.3 kg/m^2	20	21
Steel, flush pane with foamed-in polyurethane, 16 kg/m^2	27	28
Fiberglass reinforced, plastic with foamed-in polyurethane, 12 kg/m^2	25	26

Table 10.3. STC ratings for doors

The relatively low sound transmission loss of doors will significantly reduce acoustically stronger walls. For example, the common hollow door taking up 20% of a wall

having an STC of 48, will reduce the composite STC of such a wall structure to STC 27. (Check using Figure 10.4.)

The alternative solution to using an improved, expensive door is to eliminate doors wherever possible from the severely noise impacted walls and place them in other more shielded walls.

5.4 Ceilings and Roof Decks

Acoustical treatment of ceilings and roof decks is not usually necessary unless the noise is extremely severe and the sound waves pass over the building roof.

Ceilings are usually considered absorptive systems, while roof decking will provide sound barrier properties since there will generally be a layer of tar, tar paper, gravel or other materials to weatherproof the construction. Various types of roof deck systems come in different thickness and provide a different degree of sound absorption and sound attenuation depending on this thickness and on the type of built up roof-backing used.

In general, an ordinary plaster ceiling should provide adequate sound insulation, except in extremely severe cases.

6.0 GUIDELINES ON INSULATING HOUSES USING AIF METHOD

Once the noise levels outside the building are established, the requirements for adequate sound insulation for all the possible transmission paths into the building can be evaluated. Such evaluation, however, involves tedious calculations of the sound energy transmitted by various paths at various frequencies in

order to arrive at a detailed picture of the effective sound insulation required for the various rooms in a building. To simplify this procedure the National Research Council of Canada has developed simple techniques to evaluate the insulation requirements for residential housing located near transportation corridors. The appropriate building components for any room are selected on the basis of the Acoustic Insulation Factor (AIF) which is simply related to the difference in perceived noise level outside and inside. The procedures are discussed in the following sections.

Aircraft Noise

The Acoustic Insulation Factor (AIF) for aircraft noise analysis is given by:

$$\mathrm{AIF} = \mathrm{NEF}^{*}\ \text{outdoors} - \mathrm{NEF}^{*}\ \text{indoors} + 10\log_{10}N$$

N = the number of components forming the exposed facade
NEF = Noise Exposure Forecast number from aircraft flyovers
* use NEP IF APPLICABLE (10.4)

This factor, which takes account of several variables, including the number of components forming the envelope of the room, provides the link between the NEF (Noise Exposure Forecast number) indicating the sensitivity zone for aircraft flyovers and those selected components which will give adequate sound insulation. (For a further discussion of Aircraft Noise see Chapter 14.)

Road and Rail Noise

The Acoustic Insulation Factor (AIF) for road and rail noise analysis is obtained from:

$$\text{AIF} = L_A\,(\text{outdoors}) - L_A\,(\text{indoors}) + 10\log_{10}N + 2$$

where, L_A = A-weighted sound level due to traffic
N = the number of components forming the exposed facade (10.5)

General Principles

Typically, the outdoor sound may penetrate a room by several possible paths; one or more walls, windows, doors and perhaps the roof. To sum up the contributions of these various paths requires complicated calculations back and forth between AIFs and absolute powers. This complication is removed by postulating that all paths carry equal sound power. Then the AIFs (corrected for area) must simply be equal.

Although in principle one could compensate for a low AIF in one path by a superior value in another, the lowest ones always dominate, and the equal power postulate may thus be conservative by one or two points at most.

If there are several transmission paths, each must carry less power than if there were only one path. This is taken into account by increasing the AIF requirement by three points for two paths, five for three paths, six points for four paths, and so on.

The result is an optimum design that keeps the relative importance of the major construction elements in perspective. The one parameter allowed to be altered over wide limits is the ratio of window to wall area. The final step is to provide a series of tables of AIF values for typical building components.

6.1 Detailed Procedure

The appropriate building components for any room in a dwelling are selected as follows:

(a) (i) Determine by reference to the NEF/NEP contour map for the airport concerned, the NEF/NEP contour passing through the building location. If the location falls between two NEF/NEP values the higher value should be used.

(ii) Determine, either by measurement or by prediction methods, for road and rail traffic the exterior wall sound level L_A, dBA, with appropriate adjustments for sound reflections as discussed in Section 6.3.

(b) Determine whether the required AIF is for the components of a bedroom or other room.

(c) Determine the number of components which make up the exterior envelope of the room, e.g. windows, walls, ceiling/roofs and doors. It should be noted that:

(i) where windows and exterior doors do not form part of the exterior envelope of a room, they must be treated and included as a component of all rooms which have an opening or doorway opposite or adjacent to them; and

(ii) since the AIF is related to the total area of each type of component, the number of individual units of each type does not affect the determination of the AIF. For example, six individual windows in a room would be counted

as one component and their total area used in the calculations of AIF.

(d) Determine the AIF from the Tables 10.4 and 10.5 (also see CMHC guidelines).

Number of components, N, forming the room envelope	Bedrooms	Other rooms
1 component	NEF	NEF - 5
2 components	NEF + 3	NEF - 2
3 components	NEF + 5	NEF
4 components	NEF + 6	NEF + 1

Table 10.4. Selection of AIF values for aircraft noise.

(i) Adjustment factors of NEF and NEF - 5 for the sound insulation required in the building envelope have been recommended by the National Research Council of Canada based particularly on a review of studies related to thresholds of annoyance and speech interference. They are related to acceptable indoor noise levels equivalent to 0 NEF units and +5 NEF units for bedrooms and other rooms respectively. The difference of five units between the two types of accommodations allows for the desirability of having less noise in sleeping accommodation (bedrooms).

(e) In the case of road and rail traffic noise, the required AIF for an exterior wall can be obtained using the appropriate section of Table 10.5.

Noise level of building wall (dBA)	Bedrooms					Living, dining, recreation					Kitchen, bathrooms				
	Number of components forming the room envelope														
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
60	22	25	27	28	29	17	20	22	23	24	12	15	17	18	19
61	23	26	28	29	30	18	21	23	24	25	13	16	18	19	20
62	24	27	29	30	31	19	22	24	25	26	14	17	19	20	21
63	25	28	30	31	32	20	23	25	26	27	15	18	20	21	22
64	26	29	31	32	33	21	24	26	27	28	16	19	21	22	23
65	27	30	32	33	34	22	25	27	28	29	17	20	22	23	24
66	28	31	33	34	35	23	26	28	29	30	18	21	23	24	25
67	29	32	34	35	36	24	27	29	30	31	19	22	24	25	26
68	30	33	35	36	37	25	28	30	31	32	20	23	25	26	27
69	31	34	36	37	38	26	29	31	32	33	21	24	26	27	28
70	32	35	37	38	39	27	30	32	33	34	22	25	27	28	29
71	33	36	38	39	40	28	31	33	34	35	23	26	28	29	30
72	34	37	39	40	41	29	32	34	35	36	24	27	29	30	31
73	35	38	40	41	42	30	33	35	36	37	25	28	30	31	32
74	36	39	41	42	43	31	34	36	37	38	26	29	31	32	33
75	37	40	42	43	44	32	35	37	38	39	27	30	32	33	34
76	38	41	43	44	45	33	36	38	39	40	28	31	33	34	35

Table 10.5. AIF required for Road and Rail Traffic Noise Cases.

(f) It can be seen from Tables 10.4 and 10.5 that additional adjustments apply to those outlined in (d)(i) above when there is more than one component, namely; three points have to be added where there are two components; five and six points have to be added where there are three and four components respectively. These adjustments are made because as more components are added to the exterior room envelope, the total insulation is reduced.

(g) In the case of a commercial development or industrial building having office space, the Noise Assessment Unit advises that the AIF computed for "other rooms" as above be reduced by 5 AIF units in order to account for the decreased sensitivity of offices as compared to living rooms (as discussed in Chapter 14).

(h) The computed AIF must be adjusted for noise source geometry as described in Section 6.4.

(i) The tabulated values of AIF were evaluated using a particular source spectrum and typical room absorption values. The source spectrum includes three points for reflections. The computed value of AIF from subsection (h) above <u>must then be adjusted by subtracting three points from it</u>.

(j) Select the appropriate types of windows, exterior wall, ceiling-roof and exterior door respectively from Tables 10.6 and 10.9 using the obtained AIF value. Where the calculated AIF does not correspond directly to the AIF value given in the table, the next highest AIF value value should be used.

Table 10.6 - relates various types of window to AIF. Use of the table requires a calculation of the percentage of the total window area affecting a room to the total floor area.

Table 10.7 - relates various types of exterior wall construction to AIF. Use of the table requires a calculation of the percentage of total exterior wall area (less window and floors) to the total floor area.

Table 10.8 - relates various ceiling-roof constructions to AIF.

Table 10.9 - relates various types of exterior door to AIF. Use of the table requires a calculation of the percentage of the total door area affecting a room to the total floor area of that room.

Where a window or exterior door type has been determined in relation to more than one room, it shall comply with the highest insulation standard so calculated.

Tables 10.6 through 10.9 have been compiled by the National Research Council of Canada from laboratory tests on various components. These may be revised from time to time as methods and standards of construction change, and as results of a series of field tests become available and are evaluated.

(k) Where building components other than those selected on the basis of AIF (from Tables 10.6 through 10.9) are included in the building design, it is essential to investigate whether they are acoustically equivalent. Such an evaluation will require estimation of the STC value for the proposed equivalent

Window area as a percentage of total floor area of room(1)														Single glazing	Double glazing of indicated glass thickness					Triple glazing			
4	5	6	8	10	13	16	20	25	32	40	50	63	80		2 mm & 2 mm glass	3 mm & 3 mm glass	4 mm & 4 mm glass	3 mm & 6 mm glass	6 mm & 6 mm glass	3 mm, 3 mm & 3 mm glass		3 mm, 3 mm and 6 mm glass	
Acoustic Insulation Factor (AIF)(2)														Thickness	Interpane spacing in mm(3)					Interpane spacings in mm(5)			
35	34	33	32	31	30	29	28	27	26	25	24	23	22	2 mm	6								
36	35	34	33	32	31	30	29	28	27	26	25	24	23		13								
37	36	35	34	33	32	31	30	29	28	27	26	25	24	3 mm	15	6							
38	37	36	35	34	33	32	31	30	29	28	27	26	25	4 mm-6 mm	18	13	6						
39	38	37	36	35	34	33	32	31	30	29	28	27	26		22	16	13	6	6	6	6		
40	39	38	37	36	35	34	33	32	31	30	29	28	27	9 mm (4)	28	20	16	13	13	6	10	6	6
41	40	39	38	37	36	35	34	33	32	31	30	29	28		35	25	20	16	16	6	15	6	10
42	41	40	39	38	37	36	35	34	33	32	31	30	29	12 mm(4)	42	32	25	20	20	6	20	6	15
43	42	41	40	39	38	37	35	35	34	33	32	31	30		50	40	32	25	24	6	30	6	20
44	43	42	41	40	39	38	37	36	35	34	33	32	31		63	50	40	32	30	6	40	6	30
45	44	43	42	41	40	39	38	37	36	35	34	33	32		80	63	50	40	37	6	50	6	40
46	45	44	43	42	41	40	39	38	37	36	35	34	33		100	80	63	55	50	6	65	6	50
47	46	45	44	43	42	41	40	39	38	37	36	35	34		125	100	80	75	70	6	80	6	65
48	47	46	45	44	43	42	41	40	39	38	37	36	35		150	125	100	95	90	6	100	6	80
49	48	47	46	45	44	43	42	41	40	39	38	37	36			150	125	100	100			6	100
50	49	48	47	46	45	44	43	42	41	40	39	38	37				150	135	125				

Source: National Research Council, Division of Building Research, June 1980

Explanatory Notes:

1) Where the calculated percentage window area is not presented as a column heading, the nearest percentage column in the table value should be used.

2) AIF data listed in the table are for well-fitted, weatherstripped units that can be opened. The AIF values apply only when the windows are closed. For windows fixed and sealed to the frame, add three (3) to the AIF given in the table.

3) If the interpane spacing or glass thickness for a specific double-glazed window is not listed in the table, the nearest listed value should be used.

4) The AIF ratings for 9 mm and 12 mm glass are for laminated glass only; for solid glass, subtract two (2) from the AIF values listed in the table.

5) If the interpane spaces for a specific triple-glazed window are not listed in the table, use the listed case whose combined spacings are nearest to the actual combined spacing.

6) The AIF data listed in the table are for typical windows, but details of glass mounting, window seals, etc., may result in slightly different performance for some manufacturers' products. If laboratory sound transmission loss data (conforming to ASTM test method E-90) are available, these should be used to calculate the AIF.

7) For easy reference, glazing dimensions are written in the form 2 (100) 2 to denote 2 mm glass (100 mm spacing) 2 mm glass in the examples.

Table 10.6. Acoustic Insulation Factor for various types of window

	Percentage of exterior wall area to total floor area of room											Type of Exterior Wall
	16	20	25	32	40	50	63	80	100	125	160	
Acoustic Insulation Factor	39	38	37	36	35	34	33	32	31	30	29	EW1
	41	40	39	38	37	36	35	34	33	32	31	EW2
	44	43	42	41	40	39	38	37	36	35	34	EW3
	47	46	45	44	43	42	41	40	39	38	37	EW4
	48	47	46	45	44	43	42	41	40	39	38	EW1R
	49	48	47	46	45	44	43	42	41	40	39	EW2R
	50	49	48	47	46	45	44	43	42	41	40	EW3R
	55	54	53	52	51	50	49	48	47	46	45	EW5
	56	55	54	53	52	51	50	49	48	47	46	EW4R
	58	57	56	55	54	53	52	51	50	49	48	EW6
	59	58	57	56	55	54	53	52	51	50	49	EW7 or EW5R
	63	62	61	60	59	58	57	56	55	54	53	EW8

Source : National Research Council, Division of Building Research, December 1980.

Explanatory Notes :

1) Where the calculated percentage wall area is not presented as a column heading, the nearest percentage column in the table should be used.
2) The common structure of walls EW1 to EW5 is composed of 12.7mm gypsum board, vapour barrier, and 38 x 89 mm studs with 50 mm (or thicker) mineral wool or glass fibre batts in inter-stud cavities.
3) EW1 denotes exterior wall as in Note 2), plus sheathing, plus wood siding or metal siding and fibre backer board.
   EW2 denotes exterior wall as in Note 2), plus rigid insulation (25-30mm), and wood siding or metal siding and fibre backer board.
   EW3 denotes simiulated mansard with structure as in Note 2), plus sheathing, 28 x 89 mm framing, sheathing, and asphalt roofing material.
   EW4 denotes exterior wall as in Note 2), plus sheathing and 20 mm stucco.
   EW5 denotes exterior wall as in Note 2), plus sheathing, 25 mm air space, and 100 mm brick veneer.
   EW6 denotes exterior wall composed of 12.7 mm gypsum board, rigid insulation (25-50 mm), 100 mm back-up block, 100 mm face brick.
   EW7 denotes exterior wall composed of 12.7 mm gypsum board, rigid insulation (25-50 mm), 200 mm concrete.
4) R signifies the mounting of the interior gypsum board on resilient clips.
5) An exterior wall conforming to rainscreen design principles and composed of 12.7 mm gypsum board, 100 mm concrete block, rigid insulation (25-50 mm), 25 mm air space, and 100 mm brick veneer has the same AIF as EW6.
6) An exterior wall described in EW1 with the addition of rigid insulation (25-50 mm) between the sheathing and the external finish has the same AIF as EW2.

Table 10.7. Acoustic Insulation Factor for various types of exterior wall

Acoustic Insulation Factor	Type of Ceiling-Roof
41	C1
44	C1R or C1D
47	C2 or C1DR
49	C3
50	C2D
52	C2DR

Source: National Research Council, Division of Building Research, December 1980

Explanatory Notes:

1) C1 denotes 12.7 mm gypsum board, 75 mm (or thicker) insulation batts, flat roof joist and beam construction, built-up roofing.

   C2 denotes 12.7 mm gypsum board, 75 mm (or thicker) insulation batts, typical wood roof truss with ventilated attic, sheathing and asphalt roofing.

   C3 denotes paint finish, 150 mm concrete slab, 50 mm rigid insulation, built-up roofing.

2) D signifies the addition of a second layer of 12.7 mm gypsum board.

   R signifies mounting the gypsum board on wooden strapping or resilient clips.

   DR signifies the addition of a second layer of 12.7 mm gypsum board mounted on resilient clips.

3) Wherever possible ventilation openings to attic spaces should be in locations not directly exposed to the noise.

Table 10.8. Acoustic Insulation Factor for various ceiling-roof combinations [only for aircraft noise].

Percentage of total door area to total floor area of room										Type of Exterior Door
	4	5	6.3	8	10	12.5	16	20	25	
Acoustic Insulation Factor	30	29	28	27	26	25	24	23	22	D1
	34	33	32	31	30	29	28	27	26	D2
	36	35	34	33	32	31	30	29	28	D3
	37	36	35	34	33	32	31	30	29	D4
	38	37	36	35	34	33	32	31	30	D5 or D1-sd
	41	40	39	38	37	36	35	34	33	D2-sd
	43	43	41	40	39	38	37	36	35	D3-sd
	44	43	42	41	40	39	38	37	36	D4-sd
	45	44	43	42	41	40	39	38	37	D5-sd
	48	47	46	45	44	43	42	41	40	D3-D3
	50	49	48	47	46	45	44	43	42	D5-D5

Source: National Research Council, Division of Building Research, December 1980.

Explanatory Notes:

1) Where the calculated percentage door area is not presented as a column heading, the nearest column in the table should be used.
2) All prime doors must be fully weatherstripped.
3) D1 denotes 45 mm hollow core wood door (up to 20% of area glazed).
   D2 denotes 45 mm glass-fibre reinforced plastic door with foam or glass-fibre insulated core (up to 20% area glazed).
   D3 denotes 35 mm solid slab door.
   D4 denotes 45 mm steel door with foam or glass-fibre insulated core.
   D5 denotes 45 mm solid slab door.
4) sd denotes storm door of wood or aluminum with openable glazed sections.
   The AIF values apply when the glazed sections are closed.

Table 10.9. Acoustic Insulation Factor for various types of exterior door.

component and comparison to the STC value for the component selected from the appropriate Tables 10.6 through 10.9. The proposed component is considered acoustically equivalent if its STC number is equal or greater than the STC value for the component calculated from the tables.

6.2 Associated Ventilation Requirements

The AIF values are based on conventional windows and doors closed and fully weatherstripped. The effectiveness of sound insulation is considerably reduced if windows and doors are opened and left open.

Since the insulation criteria may not be met when windows are opened and in order to provide natural ventilation and remove heat build-up in the room, provision for alternative natural or mechanical means of ventilation is a basic requirement. Details of the required ventilation are presented in Chapter 14.0.

6.3 Effect of Sound Reflections

Sound reflections by the building facades were discussed in Chapter 7. Adjustment factor for the predicted noise level in outdoor living areas was also given. The details of the reflection guidelines are given in Appendix D.

Allowance must also be made for the sound reflections while specifying the building components. The adjustment is to be applied as follows;

The adjustment applies to all noise sources except aircraft noise. The outside noise level near the building facade is required to determine ventilation requirements as well as to calculate AIF [see Section 6.1.a(ii)]. To

account for the reflections from the facade 3-dB adjustments should be added to the predicted outside "free-field" sound level near the building facades.

6.4 Effect of Source Geometry

The AIF is used to select the appropriate building components if the outside noise level near the proposed building exceeds sound level limits (see Chapter 6). AIF is a composite number which is determined among others by the STC of the building component. The STC of the wall, window, roof or door is usually determined by laboratory methods where the incident sound field is diffused. Such a sound field is commonly denoted as Random Incident Field. In some instances the sound field is incident only along a narrow range of angles and the transmission loss value may decrease. An example is that of an exterior wall of a single family dwelling which is perpendicular to a roadway or a railway track (e.g. exterior surface 2 in Figure 10.11). The required AIF values in this case must be adjusted accordingly. The proper adjustment values are given in Table 10.10. (Also refer to Appendix D.)

6.5 Example

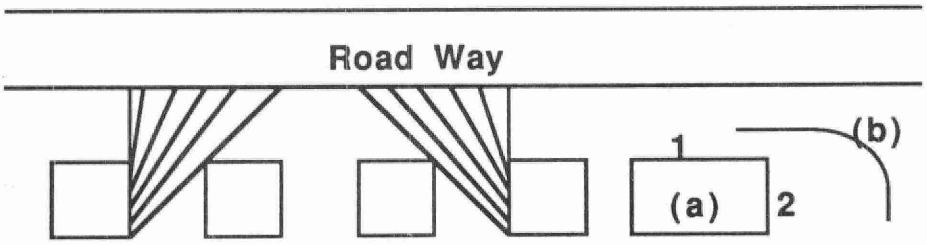
A worked example is given to illustrate the method of determining the building components for adequate sound insulation of buildings. The example concerns a proposed three bedroom bungalow. The noise source is a busy regional road. The details of the bungalow are shown in Figure 10.12.

Bedrooms one and two are chosen for illustrative purposes.

Angles at which sound arrives (0=perpendicular to surface)	Correction
60 to 90 degrees	3
40 to 90 degrees	2
30 to 90 degrees	1
0 to 90 degrees	0

(The angular range best describing the dominant noise source should be used)

Table 10.10. Correction for source geometry to be added to the required AIF.

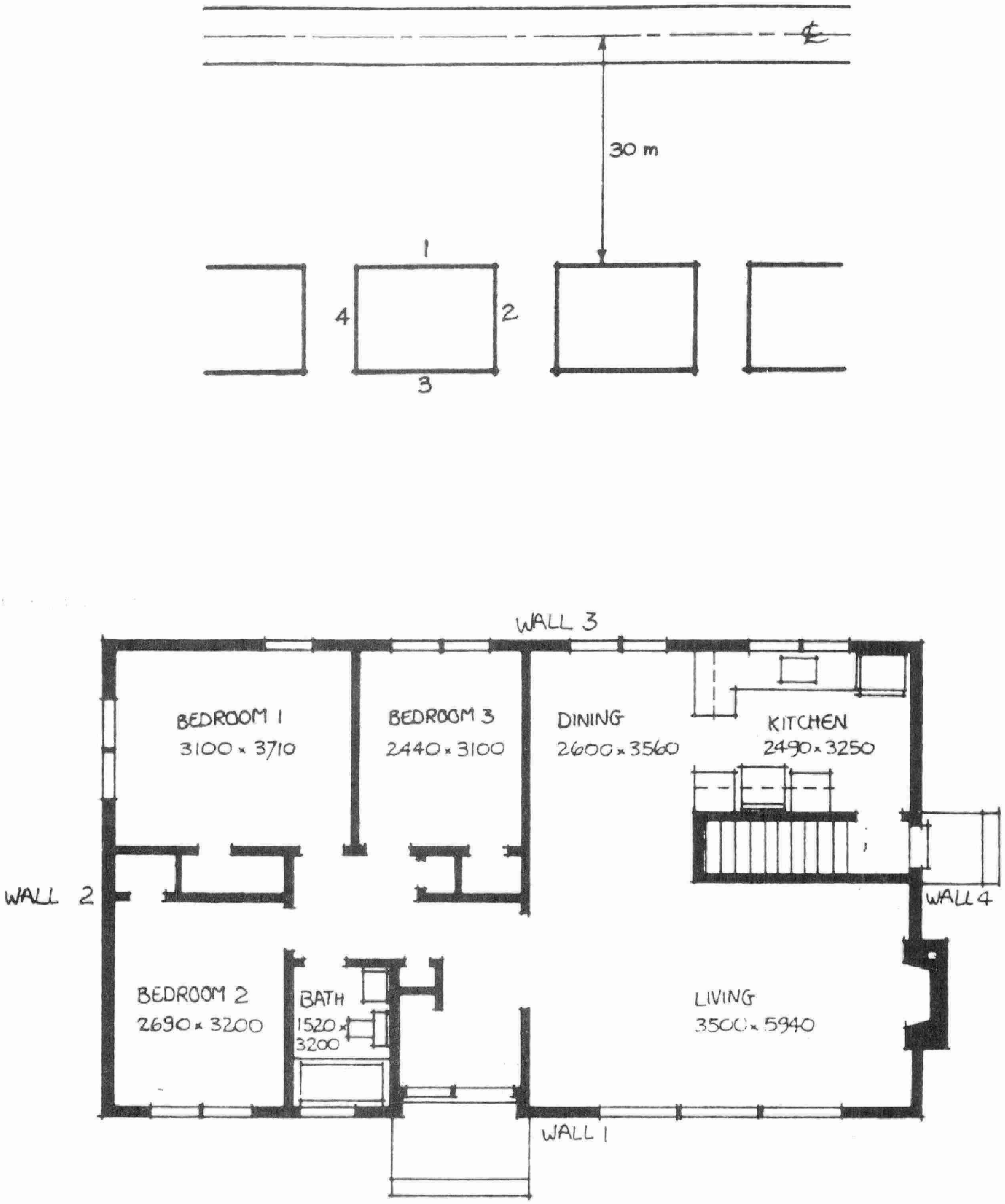


(a) Corner Lot

1,2 : Exterior Surfaces

(b) Wrap around Acoustic Fence

Figure 10.11. Sketch of a corner lot exposed to the road



ALL DIMENSIONS IN MILLIMETERS

Figure 10.12. Plan of the proposed bungalow

The amount of sound insulation that is required to reduce the exterior sound is calculated first. The five steps needed to accomplish this are presented in Worksheet 10.1.

The second stage is to select suitable components using the buildings component areas and the required AIF. The components are chosen from Tables 10.6 through 10.9. The steps required are presented in Worksheet 10.2.

The exterior walls and windows needed are commonly used materials that satisfy Ontario Building Code requirements. The builder may use any available materials in the market as long as the AIF requirements are satisfied.

6.6 Multiple Noise Sources

In the above example, AIF calculation was illustrated using road traffic as the noise source. In cases where more than one noise source impact the development, the AIF value for the component is obtained as follows:

$$\begin{aligned}\text{AIF (required)} = \text{AIF (Source 1)} \dotplus {} & \text{AIF (Source 2)} \dotplus \\ & \text{AIF (Source 3)} \dotplus \\ & \text{AIF (Source 4)} \dotplus \text{ etc.}\end{aligned}$$

where, AIF (Source 1), etc. are the design AIF calculated for each individual source and

$\dotplus$ implies logarithmic additions (e.g. 36 + 36 = 39 and not 72)

The rule of log additions was explained in Chapter 3.

* Source: Road Traffic:

Predicted Free-Field Sound Level = 62 dBA

(5dB must be added to the free-field level if the source is Rail Traffic)

STEP 1- Determine the noise level at the building facade

	WALL 1	WALL 2	WALL 3	WALL 4
Source 1	62	62	62	62
Correction for Reflections	+3	+3	-	+3
Correction for Shielding	-	-3	-15	-3
Resultant Noise Level	65	62	47	62

STEP 2 - Find number of components (ignore if level is under 55dBA)

ROOM	WALL 1			WALL 2			WALL 3			WALL 4			Total number of components
	Window	Wall	Door	Window	Wall	Door	Window	Wall	Door	Window	Wall	Door	
Living/dining	✓	✓	✓					Not Needed			✓		4
Kitchen											✓	✓	2
Bedroom 1				✓	✓								2
Bedroom 2	✓	✓			✓								3
Bedroom 3													-
Basement		✓		✓	✓					✓	✓		5

Worksheet 10.1 Calculation of AIF (page 1)

STEP 3 - Find AIF from Table 10.5

	WALL 1	WALL 2
Bedroom 1	-	27
Bedroom 2	32	29

STEP 4 - AIF adjustments for Source Geometry
(Table 10.10)

	WALL1	WALL 2	WALL 4
Source Angular Range	0-90	40-90	40-90
Adjustment	0	2	2

STEP 5 - Determine the required AIF (Add Step 3 to Step 4)

	WALL 1	WALL 2
Bedroom 1	-	29
Bedroom 2	32	31

STEP 6 - Adjusted AIF [See Section 6.1.(i)]
(Step 5 -3points)

	WALL 1	WALL 2
Bedroom 1	-	26
Bedroom 2	29	28

Worksheet 10.1 Calculation of AIF (page 2)

STEP 1 - Enter Component area
(only components of exterior walls are to be included in the calculations)

ROOM	WALL 1			WALL 2			Room Floor Area
	Wall	Window	Door	Wall	Window	Door	
Bedroom 1				6.9	1.4		11.5
Bedroom 2	4.4	1.6		7.4			8.6

STEP 2 - Find component percentages (Use values from Step 1)

Bedroom 1				60	12	
Bedroom 2	51	19		86		

STEP 3 - Select components (component % from Step 2,
and AIF values from Step 6 of Worksheet 10.1)

Bedroom 1				EW1	2mm	
Bedroom 2	EW1	3mm		EW1		

Use Tables 10.6, 10.7, 10.8 and 10.9

Worksheet 10.2 Selection of Components

7.0 INSULATION OF HOUSES USING STC METHOD

The National Research Council of Canada presented an alternate method for choosing appropriate walls, windows, etc. of exterior surfaces in late 1985. The procedure is loosely called here the STC method. The STC method has a number of advantages over the AIF method discussed in the previous section.

The STC method is discussed in detail in National Research Council of Canada publication BPN 56 (refer to Bibliography) called "Control of Sound Transmission into Buildings". The details are not presented here. Both the AIF method and the STC method are acceptable to the Ministry of the Environment.

The method is based on Sound Transmission Class (STC), (see Sections 2.0 and 3.0). STC is the most commonly used rating method for sound insulation in North America. It is better than the AIF method for the following reasons:

- The AIF method is based on a single source sound spectrum (aircraft noise) whereas the STC procedure can be used for six different common sources found in land use and can also be extended for any source with a known sound spectrum without too much difficulty.

- The AIF method assumes typical room absorption values based on a reverberation time of 0.5 sec. However, recent studies have shown that average reverberation time in Canadian homes is 0.4 sec across the frequency spectrum. The STC method, however, allows for three different room absorption values that can be used in the calculation.

- The AIF method assumes that each component of the exterior facade transmits the same percentage of the outdoor acoustic energy and corrections for dominant component are not straightforward. On the contrary, the STC method can be used to take advantage of the fact that typical walls and ceilings usually have higher STC ratings than windows and doors.

The procedure outlined (refer to BPN 56) is a simple five step method taking into consideration amount of noise reduction needed, source spectrum, source geometry, etc. The method is usually used to choose relevant components of the exterior surface. The method can also be used for reverse calculation where the noise reduction potential is determined from a given set of components. The reverse procedure is useful in evaluating the effects of modification to existing design.

A computer program (copies can be obtained directly from NRC) is also presented in the document which simplifies the use of the STC method.

CHAPTER 11

MEASUREMENT OF SOUND AND VIBRATION

1.0 MEASUREMENT OF SOUND

In order to quantitatively assess the magnitude of noise impact, it is necessary to measure the sound pressure level. This can be accomplished using a sound level meter which is an instrument consisting of a microphone, an amplifier, weighting filters, and an indicating meter. The microphone converts sound waves into a corresponding electric signal which is then amplified and modified in such a way as to provide readings of sound pressure level on the indicating meter. Usually, a control, also called an attenuator, is provided to adjust the range of sound levels that can be read, permitting the meter to be used for measurements over wide range of sound levels.

The electronic filters, such as A, B and C-weighting and frequency band, are incorporated in the sound level meter to assess the effect of noise on people. Usually, the A-weighting is used as its response characteristics corresponds most closely to the response of the ear to most types of environmental sounds. Some sound level meters are also equipped with one-octave or one-third octave-band filters to facilitate analysis of the frequency content of the measured sound.

Sound level meters commonly measure the averaged (the so-called root mean squared, RMS) level of the acoustical signal, and the response of the indicating meter is determined by preselection of one of the meter time weighting characteristics, "Slow" or "Fast". These

characteristics determine the time over which the signal is integrated to provide an averaged reading.

One of the primary differences between various sound level meters is accuracy. Technical standards specify four types of sound level meters:

Type 0 - Precision Sound Level Meter - used only for noise and vibration measurements in scientific research and development as well as for noise emission certification.

Type 1 - Precision Sound Level meter - used only in carefully controlled field environments or in laboratory work.

Type 2 - General Purpose Sound Level Meter

Type 3 - Survey Sound Level Meter - rarely used except as a quick check on noise levels.

The use of Type 0 and Type 3 sound level meters is not recommended by the Ministry of the Environment.

To verify the reliability of a sound level measurement, calibration is necessary for each set of data taken. This may be achieved by the use of a calibrator, an accurate sound source which introduces a reference sound level signal into the microphone. The procedure involves placing the calibrator over the microphone and adjusting the sound level meter until the meter reading corresponds to the reference sound pressure level.

There is a great variety of instruments available on the market, and a wide variety of applications to which they may be put.

2.0 REVIEW OF ENVIRONMENTAL NOISE INSTRUMENTATION

2.1 General Purpose Sound Level Meters

Type 2 meters usually use piezoelectric microphones and have an accuracy of at least 2 dB at 1 kHz. They usually incorporate the A, B and C weighting filters, and allow measurements over a wide range of sound levels. Occasionally, octave-band filters and detachable microphones are also incorporated. Typical examples of Type 2 Sound Level Meters are illustrated in Figure 11.1

The make and type of instruments shown are not necessarily endorsed by the Ministry of the Environment. They simply represent some common types in current use.

2.2 Precision Sound Level Meters

In general, Type 1 meters are used only in carefully controlled field environment or in laboratory work. They have accurate microphones of either the air-or electret condenser type which may be mounted remotely in order to minimize the effect of the operator and instrument case on the incident sound field. Type 1 meters can measure over a larger range of sound levels than the other two types (Type 2 and 3), and have an accuracy of at least 1 dB at 1 kHz.

In addition to "Slow" and "Fast" they are also equipped with "Impulse" and "Peak" time-weighting characteristics, which enable measurement of impact noise such as forging, stamping or gunfire noise.

An overload signal indicator is a common feature for this type of meter.

Typical examples of Precision Sound Level Meters in current use are shown in Figure 11.2

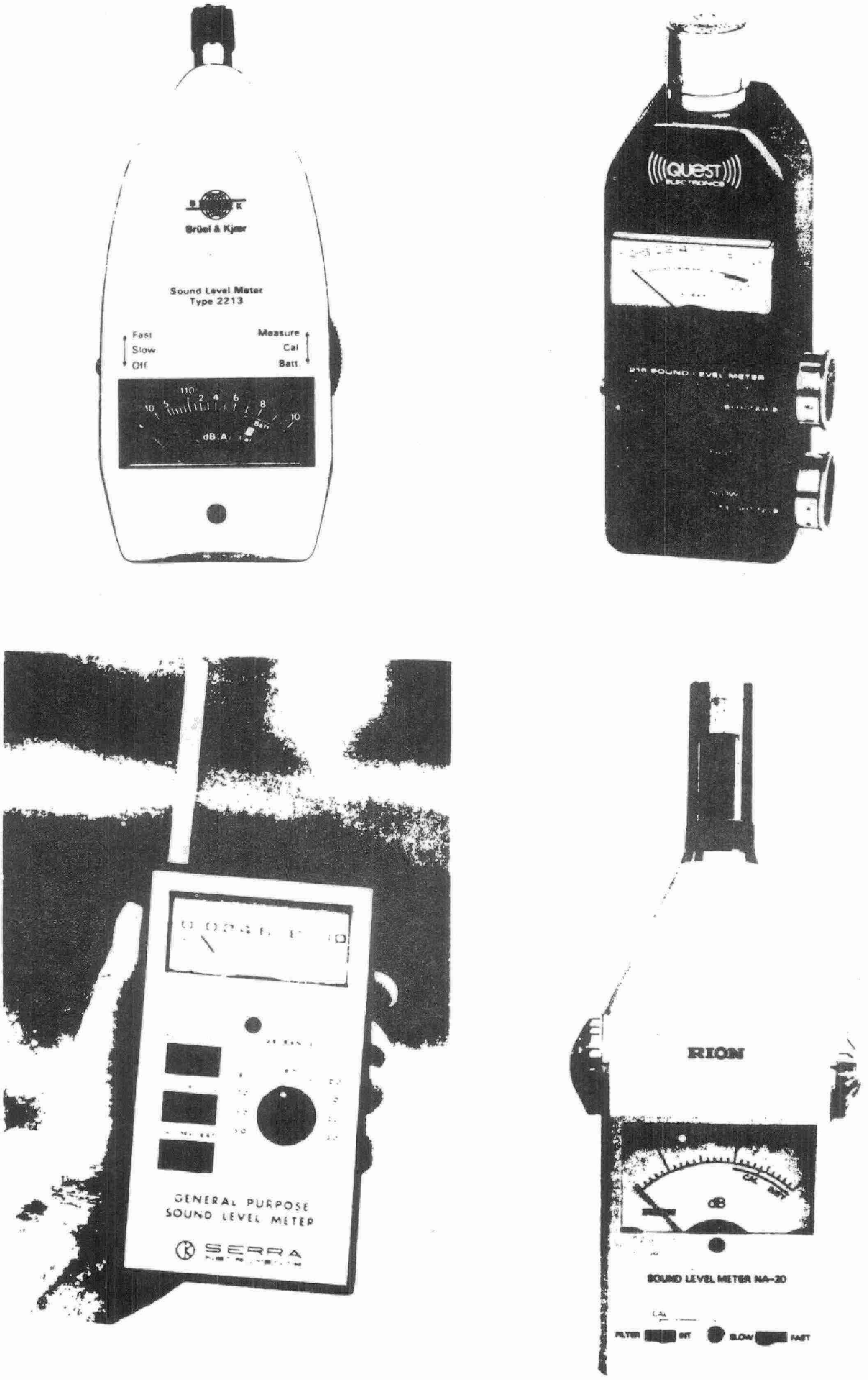


Figure 11.1 Examples of general purpose sound level meters

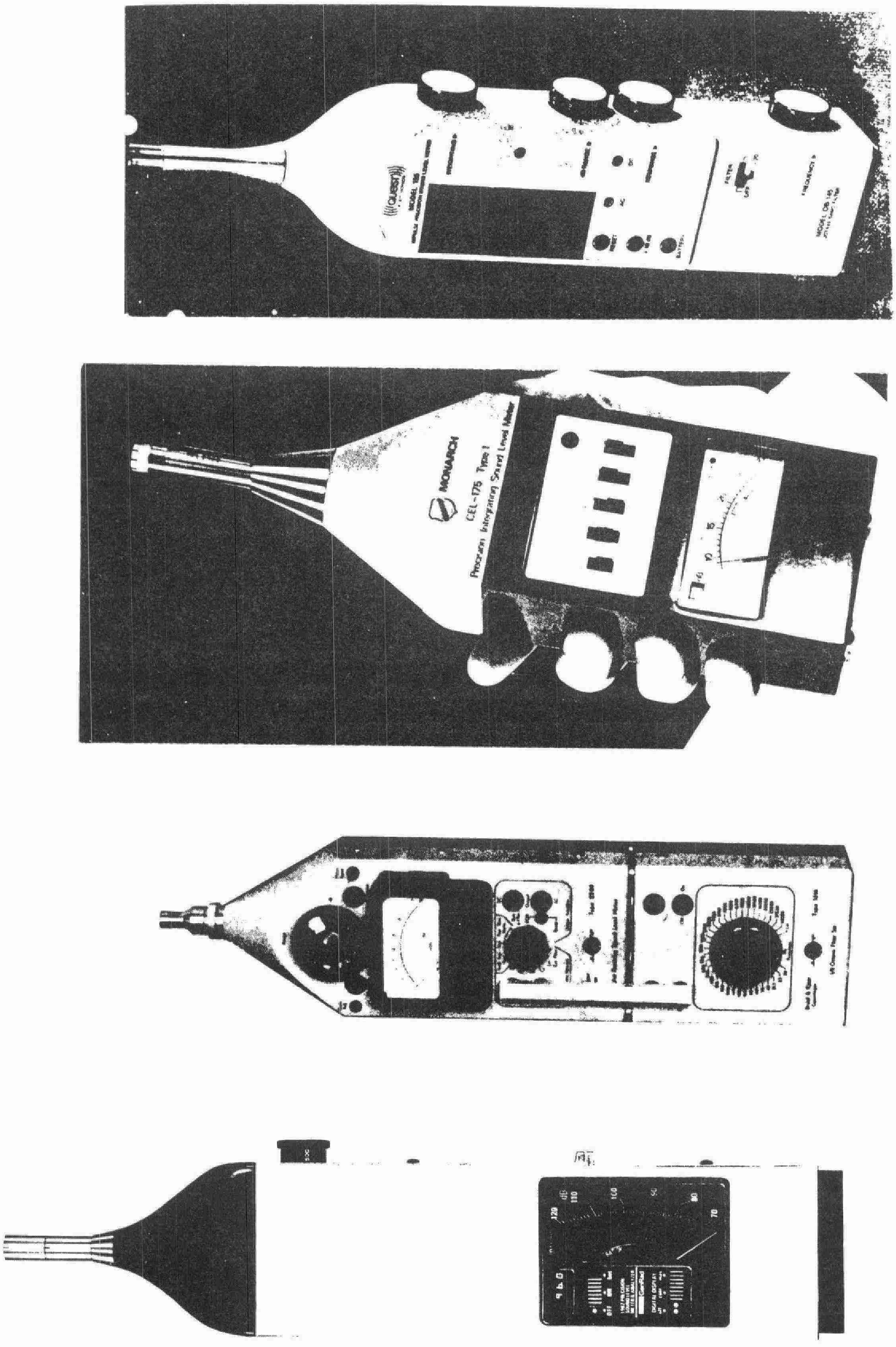


Figure 11.2 Examples of precision sound level meters

2.3 Integrating Sound Level Meters for Leq Measurements

As described earlier in this Chapter, the Conventional Sound Level Meters average the acoustic signal. The averaging time is selected by the "Slow", "Fast", "Impulse", "Peak", time-weighting characteristics incorporated in the meter.

The Integrating Sound Level Meter simply carries the averaging idea a step further by providing a much wider choice of averaging times. Instead of being limited to a maximum averaging time constant of one second (using "Slow" time-weighting characteristic of the meter), an integrating sound level meter may be capable of averaging over many minutes, hours and even days.

Another difference between the Conventional and Integrating Sound Level Meters is that the latter gives the same weight to all the earliest and latest (and all - in between) parts of the acoustical signal, while a Conventional Sound Level Meter gives greater weight to the more recently occurring part of the sound signal then to the older parts (exponential). It is important to remember the following rules:

- If a sound is constant in level, Conventional and Integrating Sound Level Meters will give identical results.

- If a sound signal fluctuates in level, the Conventional Sound Level Meter reading will fluctuate while the Integrating Sound Level Meter will average the fluctuations and produce an averaged reading.

Although a Conventional Sound Level Meter can be used to measure long-time average level, the operator must sample and record many sound level readings while making certain that in this sampling process, a significant noise event is not missed. Then, he must carry out manually the calculations of the average. The Integrating Sound Level Meter performs the measurement (integrating samples of sound signal) automatically, improving accuracy and reducing the possibility of measurement error.

Commercially available Integrating Sound Level Meters can be classified as being general application or special application. The general application instruments have a full range of operating facilities and are usually capable of measuring Leq, maximum sound level and integration time (or elapsed time). Typical examples of such instruments are shown in Figure 11.3.

The integration time can be preset for automatic operation or controlled manually, and a pause control is provided to inhibit unwanted noise events and allow integration to be taken at various locations. Full facility instruments are capable of making ordinary sound level measurements using various frequency filters and detector characteristics (i.e. "Slow", "Fast", "Impulse", "Peak"). They may also be able to operate with plotters, printers and other output devices.

The special application integrating sound level meters are usually smaller, lower cost instruments intended for special industrial and community noise measurements. They include many of the features of the general application unit but do not provide the full range of frequency weighting, detector characteristics and integration time presets. Typical examples of special application Integrating Sound Level Meters are shown in Figure 11.4.

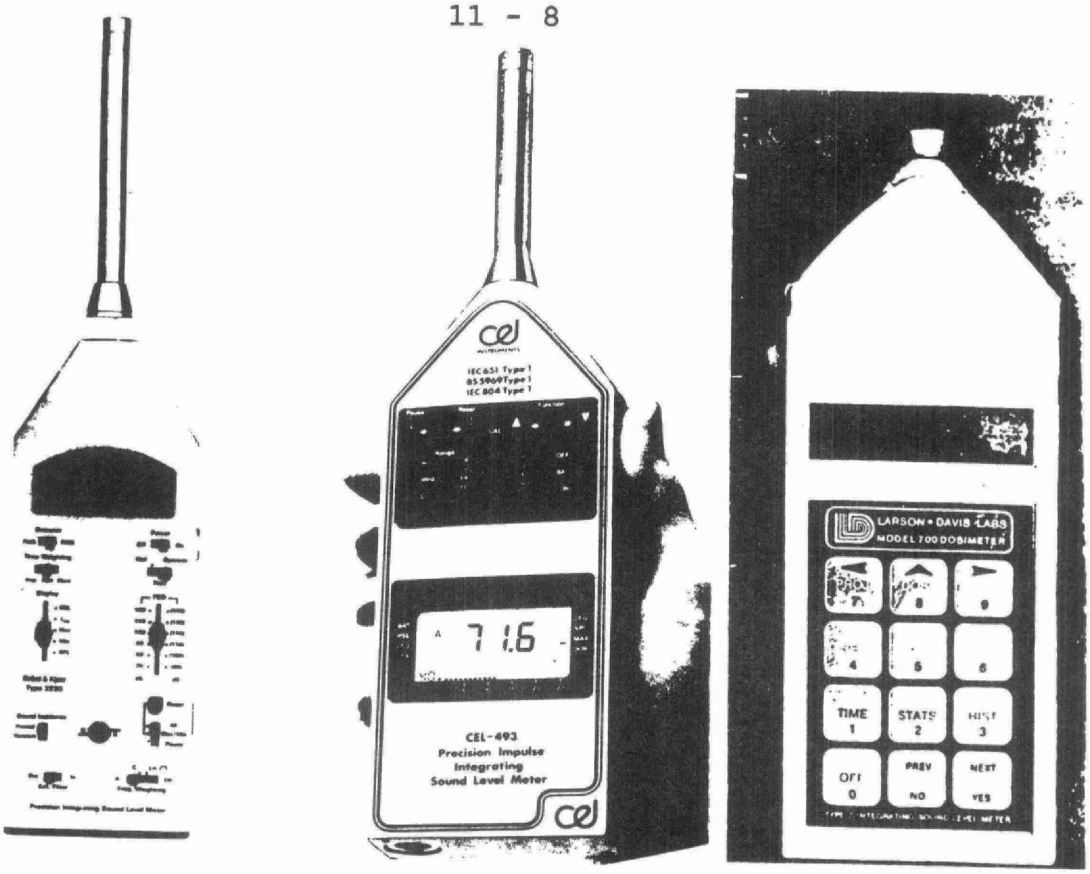


Figure 11.3. General application integrating sound level meters

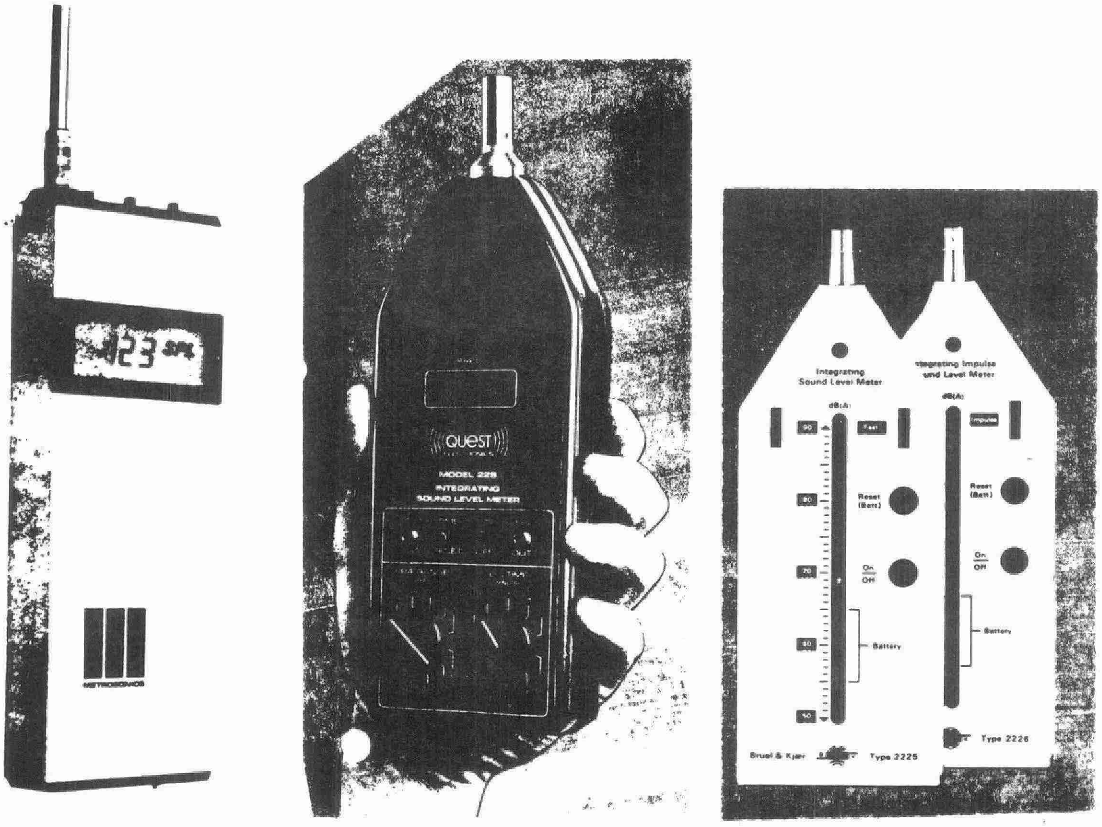


Figure 11.4. Special application integrating sound level meters

2.4 Acoustic Calibrators

In order to obtain reliable results of noise measurements, calibration checks of the sound level is required. This ensures the reproductibility of the measurement and, if properly carried out, gives correct absolute values. A sound level meter can be accurately calibrated by applying a reference source, which produces a known sound level at a specified frequency, to the sound level meter's microphone and adjusting the sensitivity (on the sound level meter) until the sound pressure level indicated by the meter agrees with the sound pressure level of the reference source (calibrator). This calibration should be performed immediately before and after measurement on location.

Most calibrators use an electrical signal to drive a diaphragm which serves as a loudspeaker in the calibration cavity. Because the calibration level is a function of the applied voltage, a regulating circuit is used to maintain this applied voltage at a constant level. Most calibrators of this type operate at 1 kHz. At this frequency, the weighting filters have no gain, offering the advantage that a 1 kHz calibrator can be used with the sound level meter in the A-weighting mode without using any correction factors. An example of a typical electrically controlled acoustic calibrator and a sound level meter fitted with the calibrator are shown on Figure 11.5.

3.0 MEASUREMENT TECHNIQUES

When performing acoustical measurements, due consideration must be given to the use of the sound level meter and to

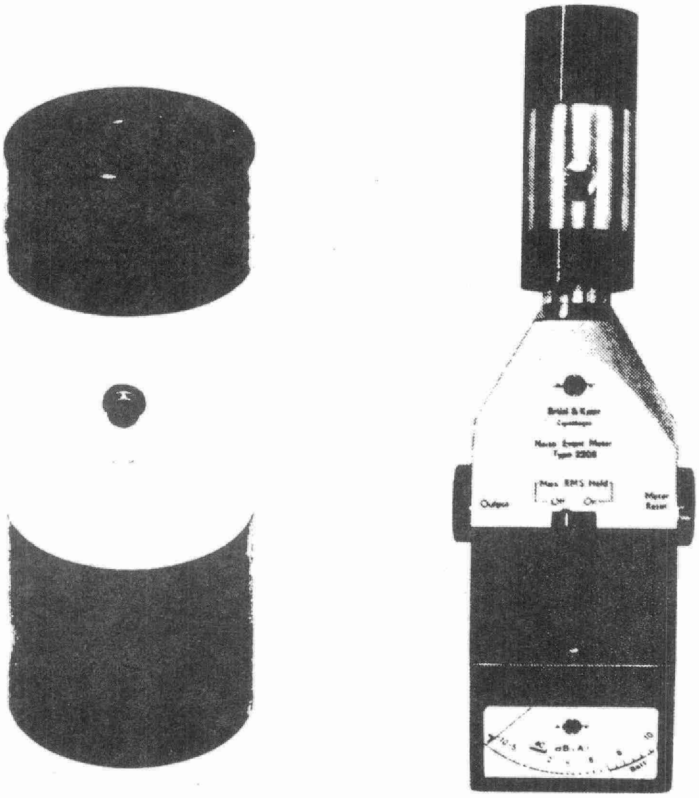


Figure 11.5. Acoustic calibrator and sound level meter fitted with the calibrator

the relationship between the instrument and the noise source. Improper use of the meter will affect the accuracy of acoustical measurements.

The key to operating a sound level meter is to use it in a manner that will not alter the sound field being measured. Also, the effect of background noise and meteorological conditions should be taken into account to ensure reliable measurement results.

The following is a more detailed discussion of these effects:

3.1 The Effect of Reflecting Surfaces

When measuring outdoor noise sources, the presence of walls, obstructions and even the operator, can affect the sound field of the source. This disturbance can cause incorrect measurements. The errors are most marked in the frequency range of 200-4000 Hz, when the physical dimensions of objects are similar to, or larger than, the wavelength of the sound.

The most effective way to avoid these errors is to select measurement sites which are far-removed from any reflecting surfaces. The meter should be held (or positioned on the tripod) away from the operator's body to prevent sound reflections. Also the operator must not be located between the meter and the noise source. In order to reduce errors due to the presence of the operator, the sound level meter may sometimes be attached to the pistol grip and held at arm's length during the measurements.

3.2 The Effect of Microphone Orientation

There are two types of microphones used in sound measurements. The first type of microphone should be pointed towards the sound source if the sound field is estimated to be coming from one direction. This is known as a free field response type.

The second type of microphone is designed to be pointed at right angles to the source (grazing incidence). These microphones are known as random-incidence response types.

3.3 The Effect of Background Noise

Background noise can cause errors in acoustical measurements whenever it is within 10 dB of the noise being measured. If the increase in the sound pressure level generated by noise source under measurement, compared to the background sound pressure level alone, is 10 dB or more, the background noise has virtually no effect, and the result of measurement is essentially the sound pressure level generated by the noise source. However, if, for example, the sound pressure level measured in the vicinity of a ventilating fan is 66 dBA, and the background level at the same location, measured with the fan shut off, is 57 dBA or higher, the result of fan noise measurement will not be reliable without special adjustments. In such a situation, it is best to reschedule the measurements until the background level on the site drops to below 55 dBA.

3.4 The Effect of Meterological Conditions

Outdoor noise measurements should not be performed in the presence of excessive wind, humidity, and outside the

temperature range specified by the manufacturer of the measuring instrumentation.

The following limitations on meterological parameters during noise measurements generally apply:

(a) wind speed in excess of 15 km/h;
(b) temperature, outside the range -10°C to 50°C;
(c) relative humidity in excess of 90%.

High wind speeds generate turbulence around the microphone. The turbulence causes pressure fluctuations which the microphone senses as sound. This "pseudo-sound" is often of sufficiently high level to mask the actual noise under investigation.

Also, sound measurements should not be attempted under conditions of temperature beyond the meter specifications. The temperature range of operation of the meter is usually quoted in the instruction manual.

High humidity conditions can cause measurement errors. Most meters are not to be used if the humidity exceeds 90%. If condenser microphones are being used, moisture can condense between the diaphragm and back plate making measurements unreliable.

In addition to the above limitations, it is a good practice to note the wind direction as the propagation of sound in air can be strongly affected by wind, especially close to the ground surface.

4.0 MEASUREMENT OF VIBRATION

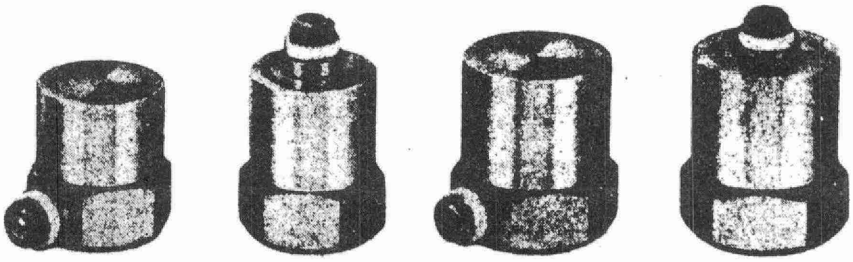
The basic vibration measurement system includes a transducer, pre-amplifier and some means of analyzing and displaying the transducer generated electrical output. Just as in sound measurements, the transducer is the most critical element in any vibration measurement system. The important characteristics of a transducer are the sensitivity, the frequency response and the linearity of the relationship between indicated and applied vibration amplitude at a given frequency. Other considerations are sensitivity to vibration in directions other than that intended to be measured and sensitivity to the environment (temperature, electrical fields, etc.). The associated electrical amplifiers, filters, integrators and recorders should have adequate frequency response, gain and linearity to ensure that they cause no distortion of the output signal.

5.0 VIBRATION INSTRUMENTATION

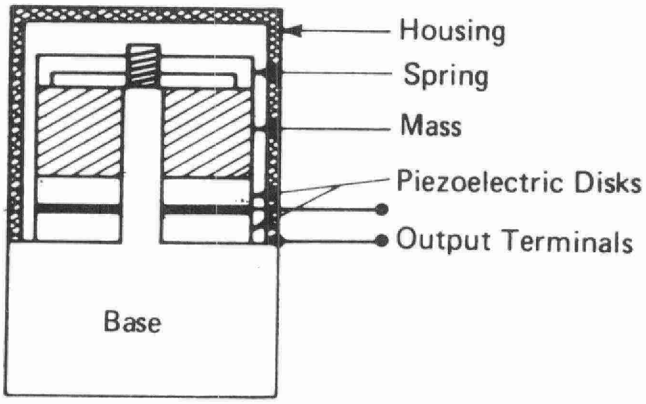
The most popular vibration transducer is the accelerometer followed closely by the vibration pick-up.

5.1 Accelerometers

The accelerometer produces an electrical signal, the voltage of which is proportional to the acceleration experienced by the device. Shown in Figure 11.6 are several commercially avaiable accelerometers along with a schematic showing basic construction and active elements. Basically, the accelerometer consists of a mass suspended on a spring between two piezoelectric crystals. These components are encased in a metal housing and attached to a base. When the assembly is mounted to a vibrating



(a)



(b)

Figure 11.6. a) Examples of commercially available accelerometers
b) Basic construction of accelerometer
and active elements

surface, the mass exerts an initial force on the crystals that is proportional to acceleration. From the piezoelectric effect of the crystals, a voltage proportional to the acceleration is produced and brought out through a connector to small easily attached cables. For accelerometers the output voltage sensitivity is usually rated in terms of millivolts per g, where g is the acceleration due to the earth's gravitational field. Typical sensitivities for commercially available piezoelectric accelerometers range from 10-60 mV/g over a wide frequency range. Accelerometers are small, lightweight, need no external voltage supply and have good high frequency response. However, they require a pre-amplifier to suitably condition their output (as do microphones).

5.2 Velocity Pick-ups

Velocity pick-ups provide an electrical signal whose voltage is proportional to the velocity of the vibrating surface to which it is mounted. The device consists primarily of a moving coil surrounded by a permanent magnet. As the coil moves due to the motion of the pick-up, a voltage is induced which is proportional to velocity. The induced signal is brought out through a connector to small easily attached cables. The velocity pick-up has the advantage of not requiring pre-amplification. However, velocity pick-ups are large devices compared to accelerometers and extremely sensitive to magnetic fields common in industrial environments. They have moving parts which are prone to wear and, due to high internal friction, are generally less sensitive than comparable size accelerometers. For all these reasons, the accelerometer is considered to be more versatile in vibration measurements. If velocity or displacement is required rather than acceleration, it can be obtained

knowing the vibration frequency, or very often the conversion to velocity and displacement from acceleration is done electronically using an integrator, so that an accelerometer can easily be used for velocity measurements.

5.3 Vibration Transducers Mounting

Perhaps the most critical aspect of the use of vibration transducers is in the mounting. If the transducer is not solidly mounted to the vibrating surface, significant measurement errors may be expected.

In Figure 11.7 are shown several common methods.

Method 1 Mounting

This method is the best in terms of frequency response, approaching a condition corresponding to the actual calibration curve supplied with accelerometer. If the mounting surface is not quite smooth, it is a good idea to apply a thin layer of silicon grease to the surface for threading down the accelerometer. This increases the mounting stiffness. It is essential whenever using a mounting screw not to tighten it fully, as one may introduce base bending affecting the sensitivity of the accelerometer.

Method 2 Mounting

This method is convenient when electrical isolation between the accelerometer and vibrating body is necessary. It employs the isolated stud and a thin mica washer. The frequency response is good due to the hardness of the mica.

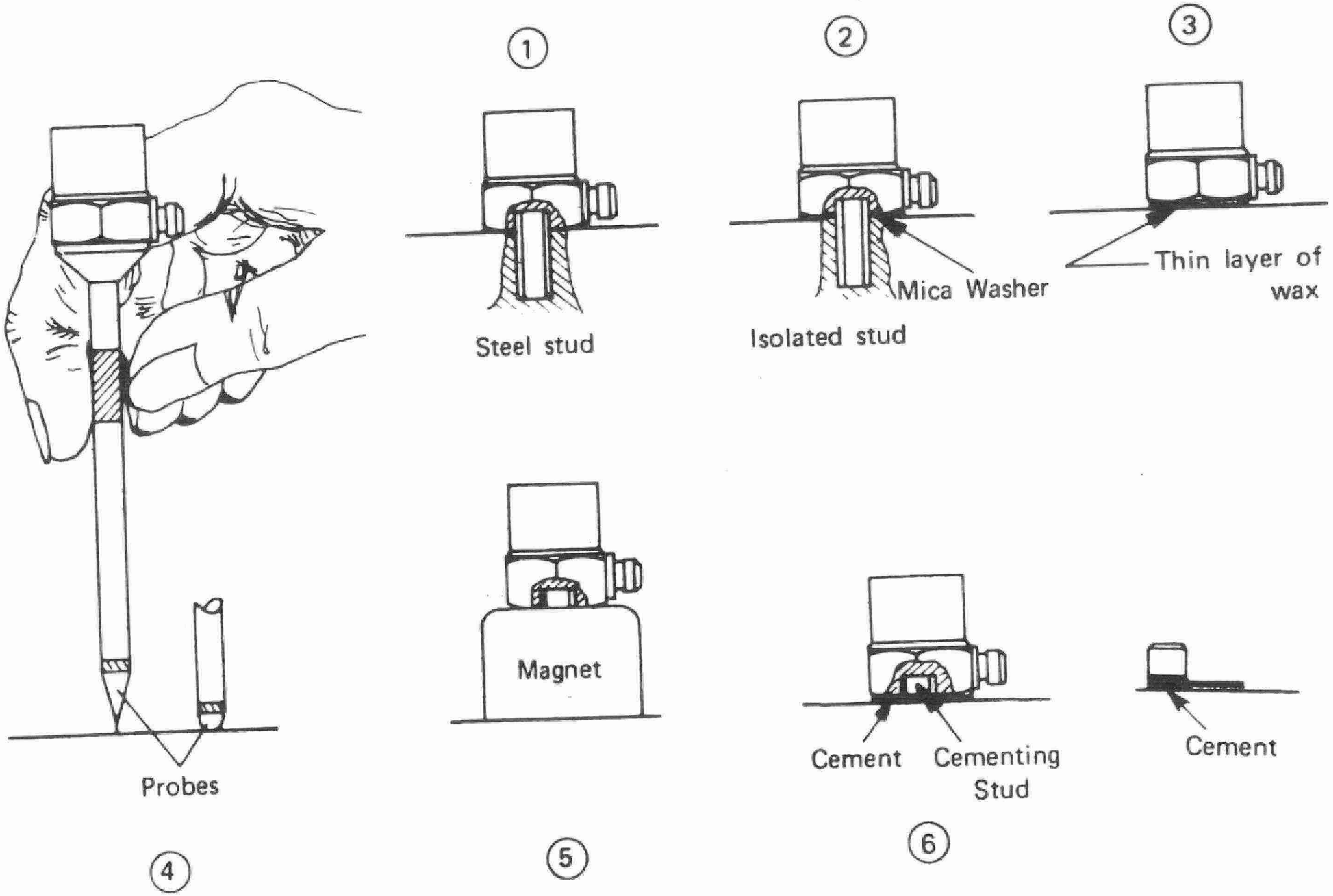


Figure 11.7. Common methods for mounting accelerometers

Method 3 Mounting

This method employs a thin layer of wax for sticking the accelerometer under the vibrating surface. Surprisingly, this method yields a very good frequency response due to the stiffness of the wax. Caution is required, however, above room temperature, as the wax melts and the method fails.

Method 4 Mounting

This method employs a probe with interchangeable round and pointed tips. The method may be convenient for certain applications but should not be used for frequencies much higher than 1,000 Hz.

Method 5 Mounting

This method employs a permanent magnet which also gives electrical isolation from the vibrating specimen. A closed magnetic path is used and there is virtually no magnetic shield at the accelerometer position. This mounting should not be used for acceleration amplitudes higher than about 200 g or temperatures above 100°C.

Method 6 Mounting

This method is convenient when a cementing technique is appropriate. If the bond is good, the frequency response of the transducer is also good.

Some care must be given to avoid cable "whip". Here some method of clamping the electrical output cable to the surface must be found to avoid high level whipping motion of the cable relative to the accelerometer. If not attached securely, the cable will often experience fatigue

failure at the terminal. Usually either wax, tape or glue, as illustrated in Figure 11.8, will be adequate.

5.4 Pre-amplifier

This component of the vibration measurement system increases the level of the transducer signal an provides and impedance matching device between the transducer and signal-processing equipment. Most transducer manufacturers supply an assortment of pre-amplifiers as optional equipment. For those measurement situations where long cable lengths are required, a charge type pre-amplifier is strongly recommended along with careful attention to the manufacturer's guidelines and directions.

5.5 Vibration Processing and Analysis Equipment

The processing and analysis equipment for vibration equipment is essentially the same as that for sound measurement. It includes an amplifier, frequency filters, a detector, an overload indicator and an indicating meter.

The amplifier provides the dual function of matching the high electrical impedance of the filters and adjusting the signal level to meet relatively narrow dynamic range of the detector circuitry. It is protected by an overload indicator that guarantees that the signal is not distorted from over driving the amplifier circuits. The detector determines which of the signal parameters RMS, Peak or Average is displayed on the meter. Usually it will be the power content of the signal that is of interest and, therefore, the RMS value of the signal is needed from the detector. An example of a typical vibration meter is shown in Figure 11.9. Tunable filters and graphic

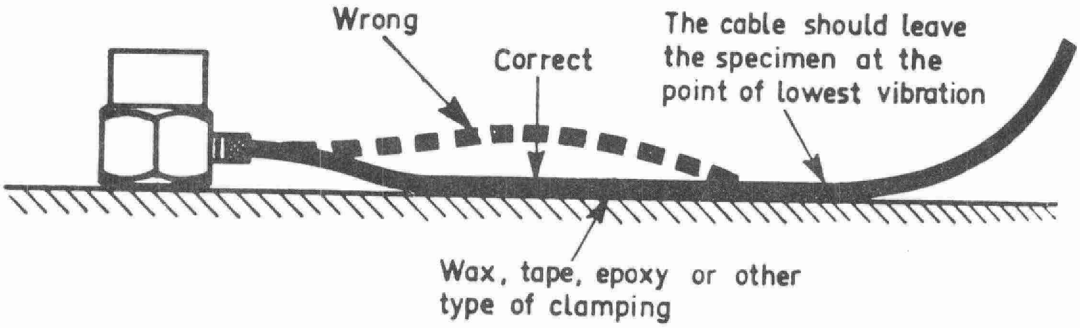


Figure 11.8. Location of cable clamping to avoid cable whip

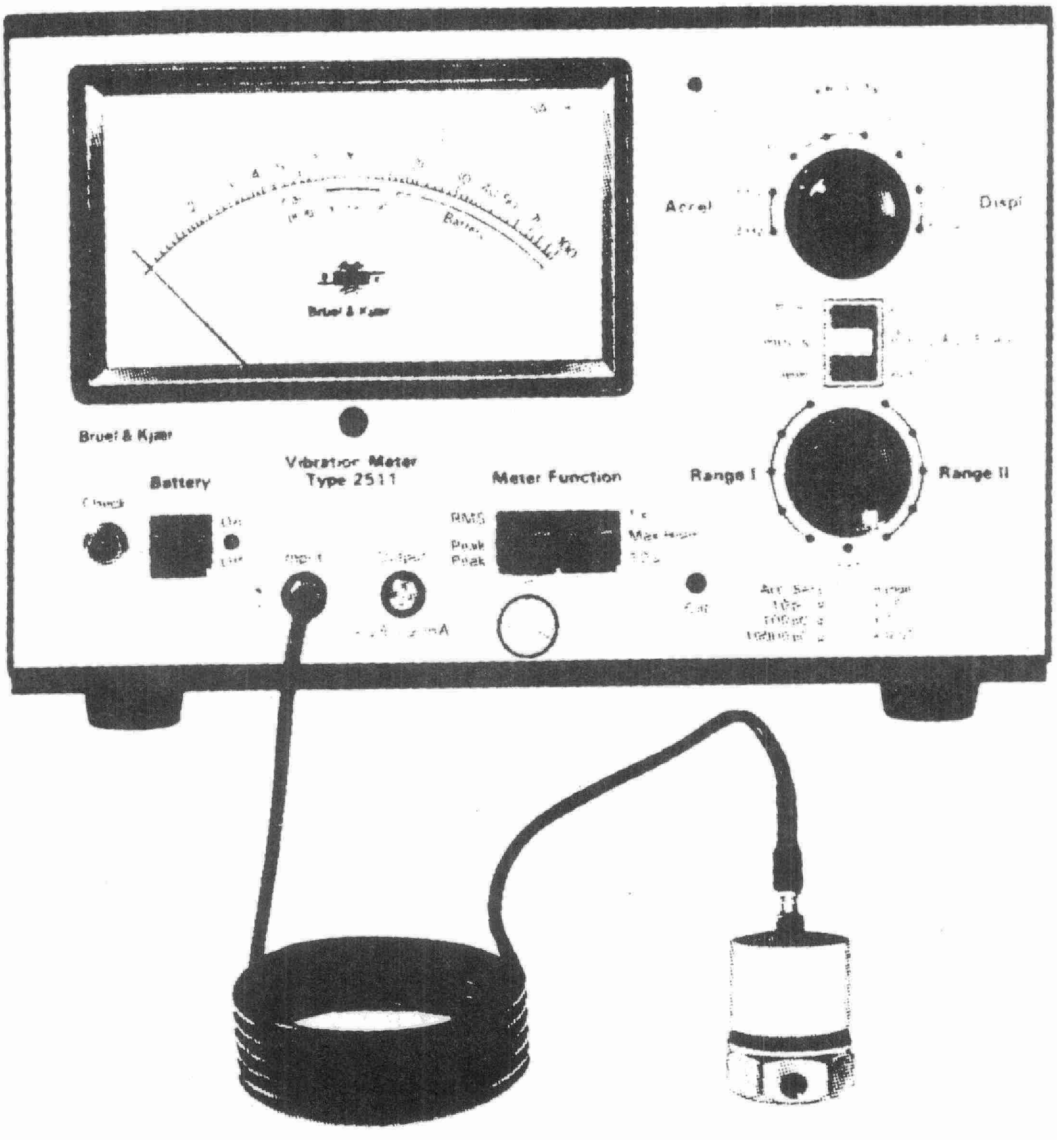


Figure 11.9. Close-up of general purpose vibration meter and accelerometer

recorders are available for making permanent records for future comparisons.

A sound level meter can also be used as a vibration meter as shown in Figure 11.10. With this system, octave band frequency analysis of vibration can be obtained and displayed in the same manner as for sound. Tape recording of the signal from the output of the sound level meter allows the vibration signals to be taken back to the laboratory for narrow-band analysis or any other further processing.

5.6 Vibration Calibrators

Every vibration transducer is individually calibrated accompanied by the calibration chart. However, in normal use, vibration transducers can be rough handled which may result in significant change in characteristics. When dropped onto a concrete floor from hand height a vibration transducer can be subjected to a shock of many thousands of g's. It is, therefore, recommended to make a periodic check of the sensitivity calibration to determine if the transducer is not damaged.

The most reliable method of calibration check is to use a calibrated vibration source designed to vibrate the transducer at a known amplitude and frequency. A typical vibration calibrator is shown in Figure 11.11. It has a small built-in shaker table and a generator which can be adjusted to vibrate at predetermined amplitude under accurately controlled frequency. The sensitivity calibration of a transducer is checked by fastening it to the shaker table and noting the output when vibrated at calibration frequency and amplitude. Calibration accuracy is usually within ±2% when used carefully.

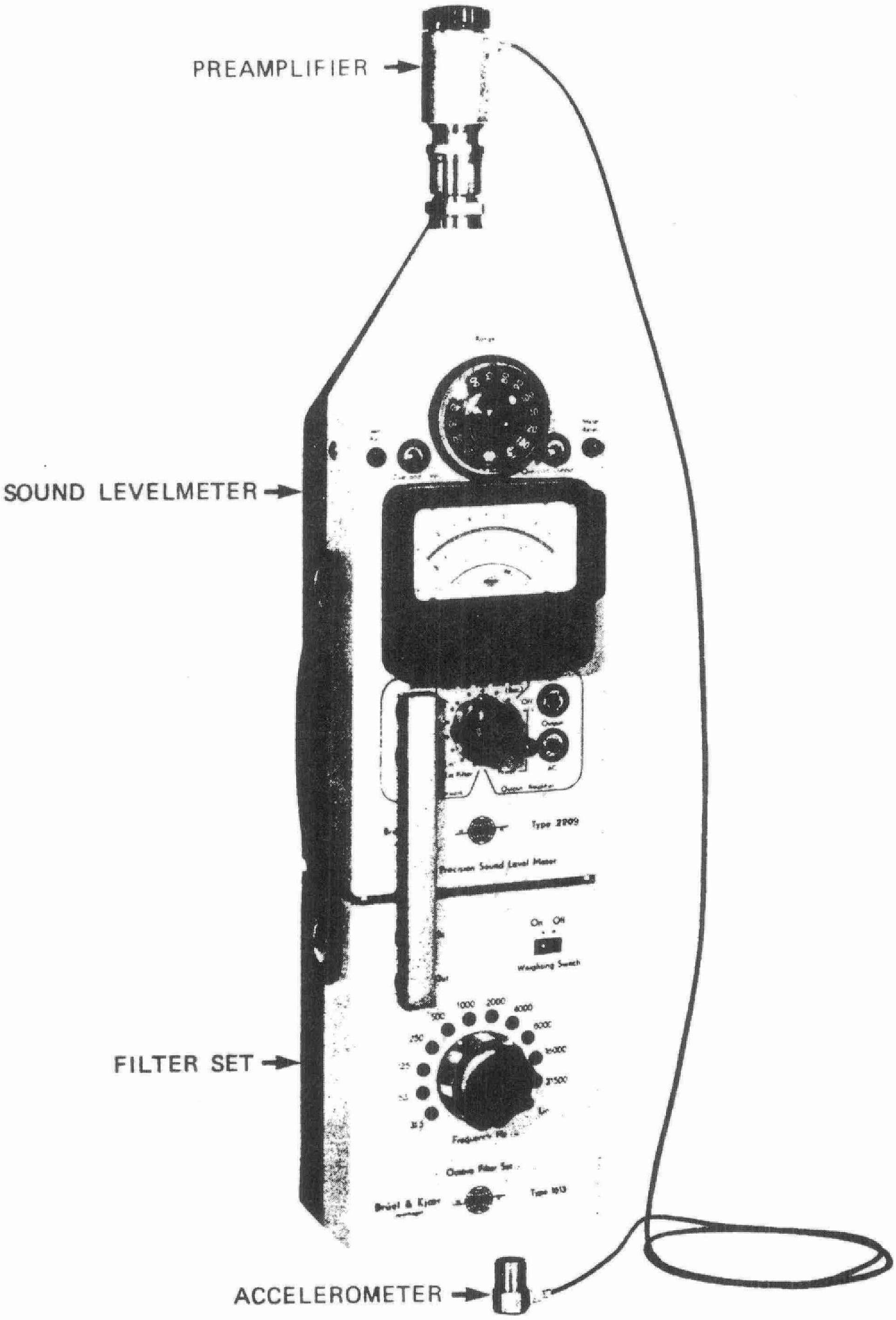


Figure 11.10. Field kit for vibration measurement

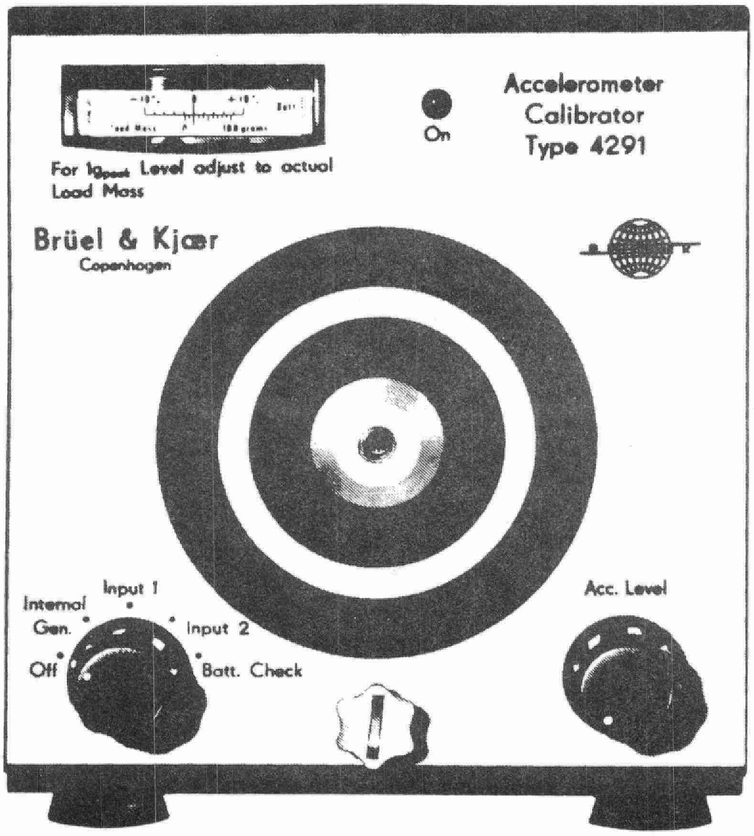


Figure 11.11. Close-up of vibration calibrator

Another application for the portable calibrator is the checking of a complete measuring or analyzing set up before the measurements are made.

CHAPTER 12

WORKSHOP 1

1.0 PROGRAM

1.1 Use a general purpose sound level meter to obtain on-site sound level measurements.

1.2 Obtain Leq values of traffic noise using various measurement techniques.

1.3 Associate sound levels and human response through direct experience.

1.4 Evaluate land use planning concepts for noise control effectiveness.

1.5 Evaluate architectural designs for noise control effectiveness.

2.0 SUMMARY OF PROPOSED ON-SITE ACTIVITIES

All trainees will be taken to various sites in Toronto to view examples of the results of architectural design/ planning of residences. The sites have been selected to provide the trainees with an opportunity to observe the effects of noise on:

(a) developments not designed/planned with regard to noise; and

(b) developments designed/planned with regard to noise.

Trainees will be required to complete worksheets during the course of the day. The worksheet instructions will require the trainee to:

(a) describe the land use of the site visited and that of neighbouring sites;

(b) identify existing dominant or potentially dominant noise sources, if any;

(c) measure noise at relevant locations using the sound level meter provided;

(d) comment on the suitability of the designated usage of the area in the light of the noise measurement results; and

(e) describe the features of the design or plan which

EITHER could have been introduced to control noise to more acceptable levels and indicate likely benefits (not only for noise),

OR have been introduced to control noise to more acceptable levels, and indicate the likely benefits in noise reduction (using the SLMs) and in other terms.

Note: Trainees are reminded that the worksheets will form part of their final assessment.

CHAPTER 13

WORKSHOP 2

1.0 SECTION A

1.1 Program

Assess the noise impact from a nearby transportation facility on a site proposed for residential development by:

1.1.1 using one or more of the prediction techniques which are available to determine the noise levels due to ground transportation; and

1.1.2 comparing the predicted noise levels to the appropriate sound level limits to determine the excess above the limit.

2.0 SECTION B

2.1 Program

2.1.1 Evaluate the magnitude of noise impact on various designated areas of a residential development adjacent to a transportation corridor.

2.1.2 Analyze physical techniques capable of reducing the noise impact on the development and investigate feasible alternatives.

2.1.3 Evaluate the effectiveness of the proposed noise abatement measures necessary to protect outdoor recreational spaces on the site.

2.1.4 Investigate insulation requirements for the proposed buildings and selection of adequate building components capable of reducing outdoor noise to the recommended maximum indoor noise levels.

CHAPTER 14

LAND USE PLANNING PROCEDURE

1.0 SOUND LEVEL LIMITS AND MINIMUM REQUIRED CONTROL MEASURES

The various sound level limits affecting the proposed land use development were discussed in Chapter 6. The Ministry publication NPC 131, "Guidelines for Noise Control in Land use Planning", containing the limits is published in the Model Municipal Noise Control By-Law.

The sound level limits provide a basis for the design of noise control measures needed in new land use plans. The noise control measures, if needed, are designed to provide a comfortable living environment both in the outdoor living area as well as the indoor living area.

A simple definition of the outdoor living area is as follows. (For complete definition, please see Ministry Publication NPC-131.) The outdoor living area is a backyard space (sheltered from noise) specifically used for recreational purposes. The suggested outdoor living area sizes are 56 m^2 (600 ft^2) for single family homes; 46 m^2 (500 ft^2) for semi-detached units; and 37 m^2 (400 ft^2) per unit for rowhousing.

Note: The Ministry does not object to having front yard living areas per se as long as the local municipality or regional municipality approves the same.

The position of the Ministry on balconies as outdoor living areas is outline below.

Balconies are treated:

(i) Not as outdoor living areas if any of the following conditions exist:

(a) not part of the floor space,
(b) indoor-outdoor sheltered living areas for communal use are provided in the complex, and
(c) if the depth is less than 4 m.

(ii) As outdoor living areas for all other cases.

No mitigation measures are required for case (i) and a provision of a warning clause would suffice. Mitigation measures are required for case (ii), but implementation difficulties must be borne in mind. Compromises may be worked out depending on the noise excess, implementation feasibilities, etc.

The above position is discussed in an internal memorandum which is reproduced in Appendix F.

The minimum noise control measures that would be acceptable to the Ministry are listed below. The list is broken down depending upon the type of noise source.

1.1 Road and Rail Traffic

1.1.1 Control Measures for Outdoor Living Areas

The sound level is determined either through predictions or from measurements with appropriate corrections during daytime hours.

If the sound level is less than or equal to 55 dBA, no measures are required.

If the sound level is between 56 and 60 dBA, either a warning clause (Clause 1) is to be provided or physical control measures are to be designed.

If the sound level is greater than 61 dBA, mitigation measures are required to reduce the level to 55 dBA. Only in cases where the acoustically required physical measures contravene local zoning by-laws or otherwise objected to by the municipality as impractical, would the Ministry allow an excess of 5 dBA with a warning clause (Clause 2), and control measures to reduce the level to 60 dBA. If a barrier is used as a physical noise control measure, its height must be such that the line of sight between the source and the receiver is broken.

1.1.2 Control Measures for Indoor Living Areas

The indoor requirements apply to two different time periods and are:

1.1.2.1 Night Time Period

The sound level is determined (either through prediction or measurements with appropriate corrections) outside bedroom windows.

No control measures are necessary if the sound level is less than or equal to 50 dBA.

If the sound level is between 51 and 60 dBA, alternate means of ventilation is required with a warning clause (Clause 3). Alternate means of ventilation usually consists of a forced air heating with the ducts sized for future installation of central air conditioning.

If the sound level is 61 dBA or greater, central air conditioning is mandatory with a warning clause

(Clause 4). In addition, windows, wall and door components must be specified.

1.1.2.2 Day Time Period

The sound level is determined (either through prediction or measurement with appropriate corrections) outside dinning room/living room windows.

Control measures are not needed if the sound level is less than or equal to 55 dBA.

Alternate means of ventilation (as discussed in Section 1.1.2.1) is required with a warning clause (Clause 3), if the sound level is between 56 and 65 dBA. Central air conditioning with a warning clause (Clause 4) is mandatory if the sound level is 66 dBA or greater.

Note: The warning clauses must be specified with the control measures. Sample wording for warning Clauses 1 to 4 are given in Appendix G, Sections 8.1, 8.2, 8.3 and 8.4 respectively.

1.2 Aircraft Flyovers

The noise impact from aircraft is usually obtained from the NEF/NEP number. The NEF/NEP numbers are usually published by Transport Canada for various airports in Canada. (See Figure 7.3.)

If the NEF/NEP value is 25-27, a warning clause (Clause 1) is the only requirement, requested by the Ministry of the Environment. The above requirement is not contained in the Provincial Policy on Airports. However, the requirement is consistent with the general philosophy of control measures specified in Table 6.5.

Alternate means of ventilation (as specified in Section 1.1.2.1) with warning Clause 3 is required for NEF/NEP values 28 and 29. In addition, window, door, wall and roof-ceiling components must be specified.

If the NEF/NEP value is between 30-35, central air conditioning is mandatory with warning Clause 4. In addition, window, door, wall and ceiling components must be specified.

Note: The aircraft noise policy permits residential development up to and including NEF/NEP value of 35. The Ministry of the Environment, however, does not recommend residential development above NEF/NEP values of 30.

2.0 LAND USE POLICY, GUIDELINES AND IMPLEMENTATION

The details of land use planning process, sound level limits and the minimum control measures required have been highlighted so far. In this section the implementation procedures will be outlined briefly.

The various stages, i.e. draft plan of subdivision, etc., at which a particular development proposal can be submitted, were described in Chapters 1 and 2. During the process, the review agencies may deem noise a concern and require a noise study to be prepared prior to approval. The noise study becomes part of the implementation procedure.

The implementation guidelines are described below, depending on the noise source.

2.1 Land Use Near Airports

Airport noise concerns are addressed in the Ministry of Housing publication "Land Use Policy Near Airports Based on the Noise Exposure Forecast (NEF) SYSTEM", March 1978, revised April 1980. The publication is produced in full in Appendix C. The basis for using NEF system and its relationship to human response was presented in Chapter 7.

The procedure for evaluating land use proposals impacted by aircraft noise is outlined in the following steps.

Step 1 - The proposed development is submitted to the approving agency.

Step 2 - The Ministry, after reviewing the proposal, requires a noise study to be prepared.

Step 3 - The noise study is prepared by the proponent's consultant, to contain:

(a) NEF/NEP values impacting the site;
(b) ventilation requirements;
(c) appropriate warning clauses;
(d) acoustical installation factors (AIF) of various rooms; and
(e) suitable choices for the wall, window, door and ceiling components.

Step 4 - The staff of the Ministry of the Environment review the noise study and the subdivision agreement.

Step 5 - Building drawings are checked by the consultant and signed under seal that all the components

meet the AIF requirements of the subdivision agreement.

Step 6 - Building permit is issued by the municipality.

Step 7 - The consultant certifies that the control measures have been properly implemented if the building inspectors are unable to do so prior to occupancy permit.

Step 8 - Occupancy permit is issued.

2.2 Land Use Near Roadways

The Ministry of Housing publication "Guidelines on Noise and New Residential Development Adjacent to Freeways" must be adhered to if the roadway is a provincial or a municipal freeway. The publication is reproduced in full in Appendix H.

The following are steps of land use implementation procedures:

Steps 1 and 2 - Same as in Section 2.1.

Step 3 - The noise study is prepared by the proponent's consultant. The contents of the noise study are:

(a) the future (at least ten year forecast) sound levels for daytime or night time periods (using prediction methods in Chapter 7);

(b) physical noise control measures such as barriers, distance setback and orientation

of the building if needed, to reduce the noise level to Ministry criteria;

(c) ventilation requirements;

(d) AIF/STC requirements of building components (procedures outlined in Chapter 10);

(e) choice of building components;

(f) appropriate warning clauses;

Steps 4 to 8 - Same as in Section 2.1.

2.3 Land Use Near Railways

The procedures for land use planning when the source is railway tracks are identical to the ones used in Section 2.2 with two modifications to be taken into account in the noise study, as follows:

(a) The sound level limits for indoor living areas are 40 dBA for bedrooms and 45 dBA for living/dining areas. To account for the locomotive noise, a penalty of 5 dBA must be used. That is, the predicted sound levels near a building facade (not in outdoor living areas) must be increased by +5 dBA.

(b) The exterior walls of structural dwellings near the railway tracks shall be built to a minimum of EW5 (brick veneer) or equivalent construction from the foundation to the rafters.

Note: EW5 is an exterior wall composed of 12.7 mm gypsum board, vapour barrier, 38 x 89 mm studs

with 50 mm (or thicker) mineral wool or glass fibre batts in inter-stud cavaties plus sheathing, 25 mm air space and 100 mm brick veneer.

2.4 Land Use Near Industrial Sources (Stationary Noise Sources)

When a sensitive land use is being proposed near an existing industry in addition to the planning act the statutes of the Environmental Protection Act must also be adhered to. Even if the development satisfies the sound level limits (including the industry), described in NPC 131, the industry may be held responsible in the future under the Environmental Protection Act for any excess noise over the ambient sound (without the industry).

There seem to be two different methods that can be applied depending on the two Acts. Ministry publication NPC-131 prescribes Leq daytime and night time limits as 55 and 50 dBA respectively in the outdoor living areas. Although the limits were meant to apply to transportation noise only, no distinction has been drawn between that and noise produced by industrial or commercial sources. Due to the Ministry's responsibilities under the Environmental Protection Act, industrial and commercial noise sources' impact is governed by sound level limits described in publication NPC-105. NPC-105 is contained in the Model Municipal Noise Control By-Law. In many instances the most stringent limit in NPC-105 is applicable implying that the subdivision may have to meet a night time Leq of 40 dBA (i.e. 10 dB lower than the NPC-131 limit).

One major solution is to separate the two land uses and not permit any sensitive land development close to an

existing industry. Such a procedure of separation distance requirement may not be practicable in many instances.

A method dealing with the apparent anomalies in applying the two Acts is under preparation by the Ministry of the Environment. Once the acceptable procedure is formulated, all concerned parties will be notified under separate cover.

2.5 Land Use Near Many Sources

A single land use development proposal may be impacted from noise from more than one noise source. A procedure was outlined in Chapter 10 to account for many noise sources when evaluating the insulation requirements.

The implementation procedure will be described by worked examples in one of the workshop sessions.

2.6 Noise Study Preparation

As described in Chapters 1 and 2, a noise study may have to be submitted at any of the stages in the planning process so that an acceptable acoustic environment can be achieved for the new land development. The general procedures describing the evaluation of noise, its impact and mitigation methods on new land use development, were outlined so far. The procedures form the basis for the preparation of the noise study. It becomes necessary to provide general guidelines for the preparation of noise study to meet the Ministry's criteria.

The Region of Peel has combined all the details together and have released a draft document entitled "General Guidelines for the Preparation of Acoustical Reports in

the Region of Peel". The document includes in its Appendix a sample copy of a noise report. The format formulated by the document is acceptable to the Ministry and is recommended that a similar format is used by everyone who is preparing a noise study. The draft document is included in Appendix G.

3.0 LAND USE PLAN REVIEW WITH RESPECT TO NOISE

The preceding discussions in this and previous chapters, presented an overview of noise concerns in land use process.

The role of the Ministry as a reviewing agency and the review process are described briefly in this section. The approving authorities are the Ministry of Municipal Affairs and/or the delegated authority. The Ministry of the Environment acts as a technical advisor expressing its concern with any of the environmental issues including noise, review and assess the noise studies as to their acceptability and present the conclusions as recommendations to the approving authorities.

3.1 General Review Process for Subdivisions, Condominiums, etc.

The Ministry of the Environment review processes are outlined below in steps.

3.1.1 The approving authority sends a copy of the land use proposal to the Ministry of the Environment for review when a developer submits a proposal.

3.1.2 The Ministry of the Environment prepares initial comments as per the flow chart. The flow chart

with the three standard conditions for draft approval is enclosed in Appendix I. The Ministry staff ensures that the proposed plan is in conformance with official plans/official plan amendments/ zoning by-law, etc. before responding to the approving authority.

3.1.3 The Ministry staff notify the approving authority of the initial comments including the recommendations for or against draft approval.

3.1.4 After draft approval has been issued, Ministry staff will verify that the requested conditions have been included in the draft approved plan. Otherwise, the staff requests an amendment to include Ministry requirements, especially if the source is a provincial highway, railway under provincial or federal jurisdiction, an airport under federal or provincial jurisdiction or a major industry.

3.1.5 The consultant/proponent is to provide a specified number of noise reports to municipality in which the development is proposed and to the approving authority, if a noise study was requested as a condition of draft approval. No time is specified for the submission of the noise reports. However, the planning process does not proceed further until all the draft conditions are satisfied. After the municipality has reviewed the report and found it acceptable, it is forwarded to the local Ministry of the Environment office and a review is requested in accordance with the conditions of draft approval.

3.1.6 The Ministry staff will review the feasibility study or the detailed noise study as required by conditions of draft approval. The review details are given in subsequent sections.

If a feasibility study is unsatisfactory to the Ministry, the Ministry staff rejects the report and recommends against the plan receiving draft approval until the noise concerns are resolved to the Ministry's satisfaction.

3.2 Feasibility Study

When the sound levels resulting from noise impacting the site are predicted to be 10 dBA in excess of the Ministry criteria, a feasibility study is recommended to be prepared and submitted to the Ministry of the Environment prior to the Ministry recommending conditions of draft approval. The main objectives of the feasibility study are to estimate the extent of the many physical control measures such as barriers, ventilation requirements, proper warning clauses and to provide some idea about the building component specification.

The feasibility study permits reassessment of the site layout including the roadways, orientation for the buildings, it provides consideration for proper rezoning including industrial, commercial, high, low and medium density residential use. The feasibility study enables the municipality to minimize potential land use conflict between incompatible land uses. The feasibility study also provides a basis where the physical noise control measures for the site can be minimized. The feasibility study determines the practicality of physical noise control measures.

The feasibility study is reviewed by the Ministry staff following the check list as shown below.

3.2.1 Check List of Requirements for Feasibility Studies

☐ 1. Intent of report (purpose) and relationship to the planning process; (prepare appropriate conditions of draft approval).

All reports to quote the file number of the approving authority.

☐ 2. Ministry of the Environment criteria for sound level limits:

(a) indoor - Leq = 40 dBA (bedroom);
(b) outdoor - Leq = 55/50 dBA (outdoor living area);

☐ 3. Identification of all major noise sources within 300 m of the proposed site, including existing and future sources.

☐ 4. Statements concerning the prediction model(s) used.

☐ 5. Statements concerning the traffic information used, source of information, etc.

☐ 6. Noise Control Measures:

- Indoor - General Statements of Intent;
- Outdoor - General Statements of Intent;

and demonstration of practicability of noise control measures.

☐ 7. Warning clause for any residual noise problem (excess of 5 dB or less).

☐ 8. If steps 1 to 7 inclusive are satisfactory to the Ministry of the Environment, then Ministry staff will recommend appropriate conditions for draft approval. Otherwise reject report and recommend against giving plan draft approval until noise concerns are resolved to the Ministry's satisfaction.

☐ 9. Copy of the report to municipality (copy to Regional Ministry of the Environment office), i.e. the concerned municipal offices should be informed by the proponent as to the recommended noise control measures and intentions.

Note: Detailed calculations are not required in this study.

3.3 Detailed Noise Study

If a detailed noise study is submitted to the Ministry for review as a part of the draft conditions, the noise study is reviewed according to the check list given below:

3.3.1 Check List of Requirements for Detailed Acoustical Reports (Land Use Proposals Seeking Final Approval)

☐ 1. Intent of report (purpose) and relationship to the planning process; (clear conditions of draft approval, site plan agreements, etc.).

All reports to quote the file number of the approving authority. Include both the date and a copy of the draft approved plan.

☐ 2. Ministry of the Environment criteria for sound level limits:

(a) indoor - Leq = 40 dBA (bedroom)
(b) outdoor - Leq = 55/50 dBA (outdoor living area);

☐ 3. Identification all major noise sources within 300 m of the proposed site including both existing and future sources.

☐ 4. Statement concerning prediction models (for road, rail, aircraft) used to determine noise levels. Include measurements for industrial or point-source noise. Give details of prediction techniques if different from Ministry of the Environment accepted procedures.

☐ 5. Supply source of traffic information (data must be accepted by the municipality):

(a) traffic volumes [present and minimum 10 years into future (vehicles/day in summer)];

(b) truck percentage (percentage heavy and medium trucks, buses, etc.);

(c) posted speed;

(d) distance from the roadway to nearest outdoor living area or proposed lot; and

(e) (i) stop and go traffic
(ii) gradient
(iii) road surface corrections
(iv) topography
(v) multi-storey buildings

☐ 6. Recommended Noise Control Measures

These measures must be in accordance with the planning objectives of the municipality. Has the report identified that the consultant had discussed the recommendations with the municipality and received their acceptance in principle?

(a) Indoor Measures

(i) If the noise level at the bedroom windows is greater than 60 dBA (i.e. 10 dBA in excess of the criteria), then central air conditioning is required. Cautionary note about location of air cooler condensor unit;

(ii) If noise level is above 50 dBA and not greater than 60 dBA, then dwelling unit has forced air heating installed with provision for central air conditioning and cautionary note regarding provision for central air and location of unit to be added to warning clause;

(iii) Window glazing to be specified either as pane thickness and air gap or minimum STC/AIF rating if noise level at window is 60 dBA or greater; and

(iv) Exterior wall specifications to be determined and listed if outdoor noise level is 60 dBA or greater.

(b) <u>Outdoor Noise Control Measures</u>

(i) Acoustical barriers, berms, berm/barrier combinations;

(ii) Location, height (relative to fixed point) of the barriers;

(iii) Surface mass density of barrier (20 kg/m^2); and

(iv) Size of outdoor living area:

56 m^2 - detached unit;
47 m^2 - semi-detached unit;
37 m^2 - row or townhouse per unit;

(v) Outdoor living area shielded by dwelling unit (front or side yard privacy area, adequately screened) - easy access to outdoor living area from inside house;

(vi) Secondary barriers;

(vii) Minimum gaps between houses;

(viii) Height of dwelling unit, i.e. 1, 1¼ and 2-storey, etc.; and

(ix) Noise levels in outdoor living areas after measures installed are to be specified.

☐ 7. Warning Clause

To be used when noise levels are not attenuated or when the levels are reduced to within 5 dBA of the criteria.

- suitable wording - including an additional phrase to cover provision for central air conditioning and location of air cooled condensor unit;

☐ 8. A summary sheet of the noise control measures and conclusions regarding their effectiveness so that the requirements can be easily inserted in the municipal agreements.

☐ 9. Appendix - showing sample calculations for noise levels and barrier calculations.

☐ 10. Confirmation that a copy of the acoustical report has been submitted to the municipality and where applicable to the approving authority such as regional government or Ministry of Municipal Affairs.

If the noise study is acceptable to the Ministry, the staff recommends that the noise control measures of the report be included in the appropriate municipal agreements.

Upon receipt of a fully executed copy of the subdivision agreement, which includes the Ministry approved noise control measures, the staff notifies the approving

authority that the Ministry recommends the release of the draft conditions for noise. In the event that the municipal staff are unable to enforce the implementation of the approved noise control measures as outlined in the subdivision agreement, a qualified professional engineer shall certify that all the drawings relating to noise matter are in conformance with the subdivision agreement prior to the issuance of the building permit. Similarly, the professional engineer should also certify that the control measures have been properly installed prior to the issuance of the occupancy permits. These recommendations must be included in the subdivision agreement.

BIBLIOGRAPHY

1. Model Municipal Noise Control By-Law Final Report, Ministry of the Environment, Ontario, August 1978.
2. R.E. Halliwell and J.D. Quirt, "Traffic Noise Prediction", Building Research Note 146, National Research Council of Canada, Ottawa, March 1980.
3. "Road and Rail Noise: Effects on Housing", Canada Mortgage and Housing Corporation, NHA 5156 81/10, 1981.
4. "New Housing and Airport Noise", Canada Mortgage and Housing Corporation, NHA 5185 81/05, 1981.
5. T.M. Barry and J.A. Reagan, "FHWA Highway Traffic Prediction Model", U.S. Federal Highway Administration, FHWA-RD-77-108, December 1978.
6. J.J. Hajek and F.W. Jung, "Simplified FHWA Noise Prediction Method", Ontario Ministry of Transportation and Communications, AE-82-05, July 1982.
7. R.W. Krawczyniuk and J.J. Hajek, "Guidelines for Noise Barrier Cost Reduction Procedure, Stamina 2.0 and Optima", Ontario Ministry of Transportation and Communications, AE-83-01, May 1983.
8. "Guidelines for Road Traffic Noise Assessment", Ontario Ministry of the Environment, December 1986.
9. "Guidelines for Railway Traffic Noise Assessment", Ontario Ministry of the Environment, 1987.
10. "Adjustment Procedures for Outdoor Sound Reflections", Ontario Ministry of the Environment, December 1986.
11. "PC-Stamson 1.1, Computer Program for Road Traffic Noise Assessment", Ontario Ministry of the Environment, November 1986.
12. "1985 Traffic Volumes on Provincial Highways", Ministry of Transportation and Communications, June 1986.
13. "Guidelines on Information Required for the Assessment of Blasting Noise and Vibration", Ontario Ministry of the Environment, 1985.
14. Draft of Proposed Publication NPC-207, Ontario Ministry of the Environment, 1983.

15. J.D. Quirt, "Sound Levels Around Buildings Near Roadways", Canadian Acoustics, Volume 10, No. 1, 1982, pp. 13-18.

16. J.D. Quirt, "Sound Fields Near Exterior Building Surfaces", Journal of the Acoustical Society of America, Volume 77, No. 2, 1985, pp. 557-566.

17. J.D. Quirt, "Basic Problems on Designing to Control Noise Insulation", Paper HH3, Presented at the 112th Meeting of Acoustical Society of America, December 1986.

18. J.S. Bradley, "Acoustical Measurements in Some Canadian Homes", Canadian Acoustical Journal, Vol. 14, #4, 1986, pp. 19-21 and pp. 24-25.

19. H.J. Sabine, M.B. Lacher, D.R. Flynn and T.L. Cluindry, "Acoustical and Thermal Performance of Exterior Residential Walls, Doors and Windows", National Bureau of Standards, Washington, D.C., 1975.

20. J.D. Quirt, "Controlling Sound Transmission into Building", National Research Council of Canada, B.P.N.-56, 1985.

21. J.D. Quirt, "Sound Transmission through Windows I. Single and Double Glazing," Journal on the Acoustical Society of America, Vol. 72, 1982, pp. 834-846.

22. J. Goldstein, "Descriptors of Auditory Magnitude and methods of Rating Community Noise", Community Noise, ASTM STP 692, 1979, pp. 38-72.

23. Standard Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions. American Society for Testing and Materials E90-81.

24. Standard Method for Measurement of Airborne Sound Insulation in Buildings. American Society for Testing and Materials E336-77.

25. Standard Classification for Determination of Sound Transmission Class. American Society for Testing and Materials E413-80.

26. Standard Guide for Field Measurement of Airborne Sound Insulation of Building Facades and Facade Elements. American Society for Testing and Materials E966-84.

27. Guide to the Evaluation of Human Exposure to Vibration in Buildings. American National Standard ANSI S3.29-1983.

28. Guide for the Evaluation of Human Exposure to Whole-Body Vibration. International Standard ISO 2631-1978(E).

29. Acoustic Noise Measurements, Bruel and Kjaer, January 1979.

30. Handbook of Noise Measurement. General Radio Company, 1972.

31. L.L. Beranek, "Acoustics", Acoustical Society of America, 1986.

32. L.L. Beranek, "Noise and Vibration Control", McGraw-Hill Book Company, 1971.

33. "General Guidelines for the Preparation of Acoustical Reports in the Region of Peel", Draft Report, Planning Department, Region of Peel, Ontario, December 1986.

APPENDIX A

GUIDELINES FOR ROAD TRAFFIC NOISE ASSESSMENT

GUIDELINES
FOR
ROAD TRAFFIC NOISE ASSESSMENT

ONTARIO MINISTRY OF THE ENVIRONMENT
ENVIRONMENTAL APPROVALS AND LAND USE PLANNING BRANCH
JULY 1986

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6 APPENDICES

1 INTRODUCTION

This report is a simplified guideline manual for the prediction of road traffic noise. It presents the procedure required by this Ministry for the prediction of equivalent sound levels, L_{eq}, due to road traffic. This procedure is to be used for land use planning, approvals of new installations or abatement.*

The prediction model is based on an enhanced and simplified version of a procedure developed by the U.S. Federal Highway Administration.** Results of studies conducted to determine the prediction accuracy of the model on Ontario roadways have indicated that, within the limitations described in Section 4, the average difference between the measured and predicted sound levels is about 2 dBA.

The manual is structured in the following manner:

> Sections 2 and 3 contain step-by-step instructions on the method used to calculate sound levels due to road traffic.
>
> Section 4 contains limitations of the prediction model in terms of traffic speed, distance, volume and topography.
>
> The final section contains a sample calculation. The calculation is performed through the use of tables and traffic noise prediction worksheets.

---

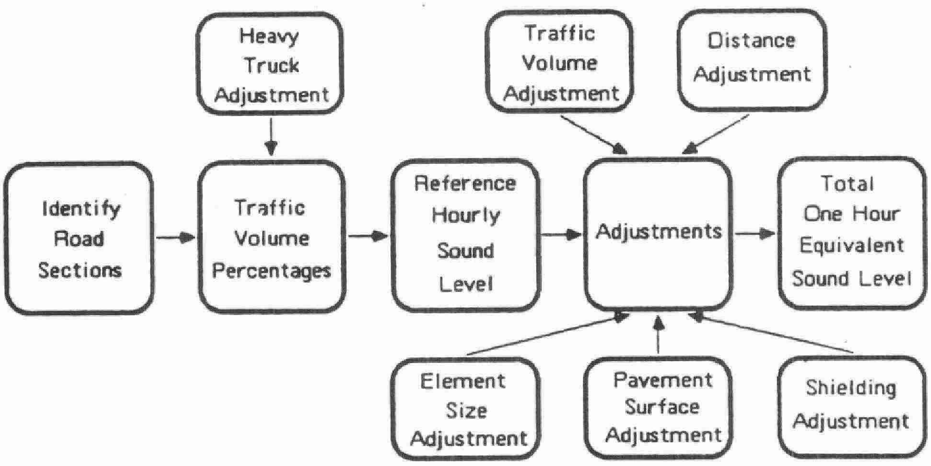
* In complex situations involving multiple roadways, multiple shielding mechanisms and/or varying topography, it is more appropriate to utilize a computer program available from the Noise Assessment Unit, Ministry of the Environment.

** Bibliography and theoretical background are contained in a separate document.

2 TRAFFIC SOUND LEVEL FOR A SINGLE ROADWAY

The following procedure shall be used to calculate the One Hour Equivalent Sound Level at a point of reception due to traffic on a single roadway. The tables used in the calculations are contained in Appendix A.

Procedure Summary



2.1 <u>Identification of Road Sections (Elements)</u>

(a) Where a roadway extends for large distances on either side of the point of reception, the calculation shall assume that the roadway extends, in each direction, at least six times the perpendicular distance from the point of reception to the roadway centre.

(b) A roadway of less than four lanes shall be represented by a series of straight line sections along its centre.

A roadway having a total of four lanes or more shall be divided into one or more sets of lanes for each direction of traffic flow. A maximum number of four lanes should be included in one set. Each set of lanes shall then be

represented by a series of straight line sections along its centre.

(c) A section of road shall be as long as possible but short enough to ensure that the following variables are approximately constant along its length:

- road alignment;
- road gradient (if heavy trucks are present);
- pavement surface type;
- traffic flow conditions:
  - ° total traffic volume
  - ° traffic composition
  - ° posted speed limit
- attenuation mechanisms:
  - ° ground absorption
  - ° shielding

2.2 Sound Level from a Single Road Section (Element)

The following calculations shall be used to determine the One Hour Equivalent Sound Level contribution from each road section. The method employed in deriving one hour traffic volumes from average daily traffic volumes is described in Appendix C.

(a) Traffic Volume

Traffic volumes can be obtained from the following sources:

(i) Annual MTC Reports, "Provincial Highways, Traffic Volumes" published by the Highway Program Planning Office, and "Commercial Vehicle Travel Data" published by the Transportation Demand Research Office.

(ii) Traffic Department of the local municipal office.

(iii) Individual Traffic Volume Count. Vehicles shall be counted for at least 20 minutes and the time interval of observation shall be noted. The total traffic volume, in vehicles per hour, is the number of vehicles counted divided by the time interval represented as a fraction of an hour.

If the total one hour traffic volume based on a traffic count of at least 20 minutes is less than 40 vehicles per hour, vehicles shall be counted for the full one hour period. If the full hour count is still less than 40 vehicles, this noise prediction method is not to be used.

The vehicles considered shall be placed into one of the following categories:

° Automobiles - all vehicles having two axles and four wheels designed primarily for transportation of nine or fewer passengers or transportation of light cargo (e.g. vans, light trucks). Generally, the gross vehicle weight is less than 4500 kilograms.

° Medium trucks - all vehicles having two axles and six wheels. Generally, the gross vehicle weight is greater than 4500 kilograms but less than 12,000 kilograms.

- Heavy trucks - all vehicles having three or more axles and designed for the transportation of cargo. Generally, the gross vehicle weight is greater than 12,000 kilograms. (Buses, although two axle vehicles, are included in this category).

(b) Adjusted Volume of Heavy Trucks

The adjustment shall be made by multiplying the percentage of heavy trucks travelling in the up-grade direction by an adjustment factor given in Table 1. The adjustment shall be applied only where the total vertical distance from the bottom to the top of the grade is at least 6 metres, and on roads having gradients of 2% or more. The adjusted percentage of heavy trucks shall then be converted to an adjusted volume.

(c) Percentage Trucks (Medium + Heavy)

The combined volume of vehicles classified as medium trucks and heavy trucks (adjusted if required) shall be expressed as a percentage of the total hourly traffic volume which was determined in Subsection 2.2(a).

(d) Percentage of Medium Trucks

The volume of vehicles classified as medium trucks shall be expressed as a percentage of the total volume of trucks (medium and heavy) determined in Subsection 2.2(c).

(e) Reference Hourly Sound Level

The Reference Hourly Sound Level at the reference distance of 15 metres from the centreline of the road section and the reference volume of 40 vehicles per hour shall be determined using Tables 3 through 6. Where the actual percentage of trucks (medium + heavy) is not provided, the nearest value shall be used.

(f) Measurement of Distance

The distance (in metres) between the point of reception and the centreline of the road section shall be measured along the shortest line joining the point of reception to the centre of the road section or its extension.

(g) Adjustments

The following adjustments shall be made to the Reference Hourly Sound Level.

(i) Adjustment for Traffic Volume

Table 2 gives the adjustment for traffic volume to be added to the Reference Hourly Sound Level.

(ii) Adjustment for Distance

Table 7 shall be used to adjust for distance and for the type of ground surface between the point of reception and the centreline of the road section.

"Reflective Surfaces"

Water, ice, asphalt, gravel, earth or other hard-packed surfaces are sound reflective.

If more than half of the ground surface between the centreline of the road section and the point of reception is sound reflective, the adjustment for distance and for the type of ground surface shall be determined using the section of Table 7 for Reflective Surfaces. The adjustment shall be added to the Reference Hourly Sound Level.

"Other Surfaces (Non-Reflective)"

If less than half of the ground surface between the centreline of the road section and the point of reception is sound reflective, the adjustment shall be dependent on the total effective height. The total effective height shall be determined by adding together the height of the point of reception above the ground, the effective height of shielding between the source and the receptor, (typical situations shown in Table 7), and the effective source height of road traffic obtained from Table 8. The adjustment shall be determined using the section of Table 7 for Non-Reflective Surfaces and shall be added to the Reference Hourly Sound Level.

(iii) Adjustment for Road Element Size

The adjustment for road element size is based on the angle subtended at the point of reception by the roadway section, see Table 10. The adjustment for road element size will also be dependent on the major type of ground surface within the sector.

"Reflective Surfaces"

Table 9 shall be used to determine the adjustment for road element size if more than half of the ground surface within the sector is sound reflective. The adjustment shall be added to the Reference Hourly Sound Level.

"Other Surfaces (Non-Reflective)"

Adjustment for Non-Reflective surfaces is considered only if the total effective height is less than 10 m. If the total effective height equals or exceeds 10 m or a barrier separates road element from receptor, adjustment in Table 9 applies.

Table 10 shall be used to determine the angular relationship between the road section and the point of reception. Adjustments for various combinations of angles can be determined from Table 11. The adjustment shall be added to the Reference Hourly Sound Level.

The minimum value of the adjustment equals -1 dBA which corresponds to a subtended angle of 180°.

(iv) Adjustment for Pavement Surface Type

An adjustment for the effect of road pavement surface shall be applied only on road sections having posted speed limits equal to or greater than 80 km/h. The adjustment shall be obtained from Table 12.

(v) Adjustments for Shielding

Shielding can be provided by vegetation, rows of houses or by a solid obstacle (barrier).

Dense Woods*

An adjustment for the attenuation by trees shall be made if and only if the woods are very dense, i.e. there is no visual path between the receiver and the road section (may not hold for deciduous trees in winter), and if the trees extend at least 5 metres above the line-of-sight. Table 13 gives the adjustment for shielding provided by dense woods.

Rows of Houses*

Table 13 gives the adjustment for shielding provided by rows of houses.

---

* When a receiver is shielded by dense woods or rows of houses, the ground surface must be considered "reflective".

Barriers**

Appendix B shall be used to obtain the adjustment for attenuation provided by any solid obstacle.

Combined Shielding Mechanisms

Where several types of shielding exist, the adjustments are additive up to a maximum attenuation of 20 dBA. In addition, the combined effects of dense woods and rows of houses are only additive up to a maximum of 10 dBA.

(h) Resultant Sound Level Contribution

The One Hour Equivalent Sound Level at the point of reception due to traffic on a road section is the Reference Hourly Sound Level as determined in 2.2(e) and adjusted according to 2.2(g).

2.3 Determination of Total Sound Level

The total One Hour Equivalent Sound Level at the point of reception due to traffic on a single roadway shall be determined by combining the sound level contributions from each road section using the rule for addition of sound levels in Table 14.

** Where two or more barriers intersect the line-of-sight between the source and receiver, it is a conservative practice to employ only the most effective barrier.

3 TRAFFIC SOUND LEVEL FOR MULTIPLE ROADS

The One Hour Equivalent Sound Level at a point of reception due to traffic on multiple roads shall be calculated by combining the sound levels resulting from each individual roadway as per Section 2. The individual One Hour Equivalent Sound Levels from the contributing roads shall be combined using the rule for addition of sound levels in Table 14.

4 LIMITATIONS

The method for prediction of traffic noise described herein is not applicable when:

(i) The distance from the point of reception to the centreline of any road section is less than 10 m.

(ii) The posted speed limit of traffic is less than 40 km/h.

(iii) The hourly traffic volume is less than 40 vehicles per hour.

In addition, the prediction accuracy may decrease where:

- the topography is very irregular (e.g. many different intervening man-made or natural obstructions or substantial variations in ground cover);
- the distance from the point of reception to the centreline of any road section is less than 15 m;

- the roadway has substantial variations in alignment (horizontal/vertical) or pavement surface;
- the roadway features interchanges/intersections, ramps, etc;
- substantial differences exist between the speeds of cars, medium trucks and heavy trucks.
- posted speed limit is less than 50 km/h.

It is advisible to use a comprehensive noise prediction model in the above specified cases.

5 SAMPLE CALCULATIONS

This section contains sample calculations of the One Hour Equivalent Sound Level, Leq(h), generated by road traffic. The calculations were performed through the use of tables and noise prediction work sheets.

PROBLEM

Refer to Figure 1. Using the information provided, determine the One Hour Equivalent Sound Levels, $L_{eq}(h)$, at the receiver due to traffic on the highway before and after barrier construction.

The road is flat (no gradient), infinitely long and paved with typical asphalt. The road and the surrounding terrain are at the same grade; the ground is non-reflective. The receiver is located 1.5 metres above ground. The barrier is 3 metres high.

SOLUTION

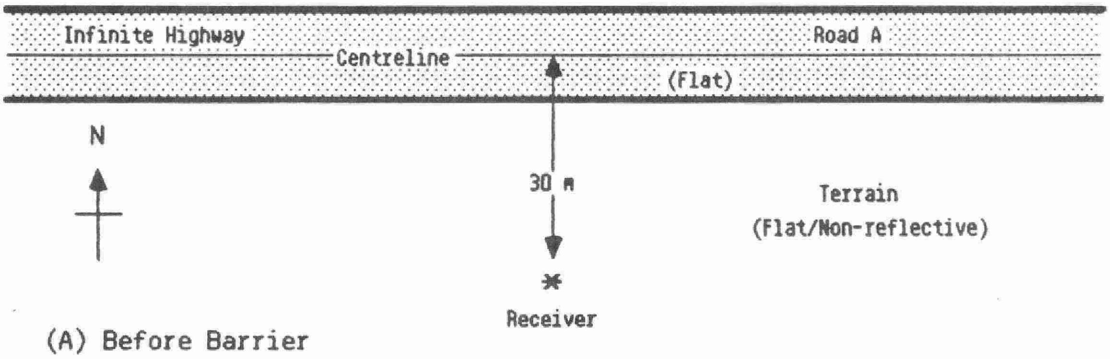
The traffic sound levels before and after the barrier is constructed have been calculated on separate work sheets. Refer to Figures 2 and 3.

5.1 Before Barrier Sound Level

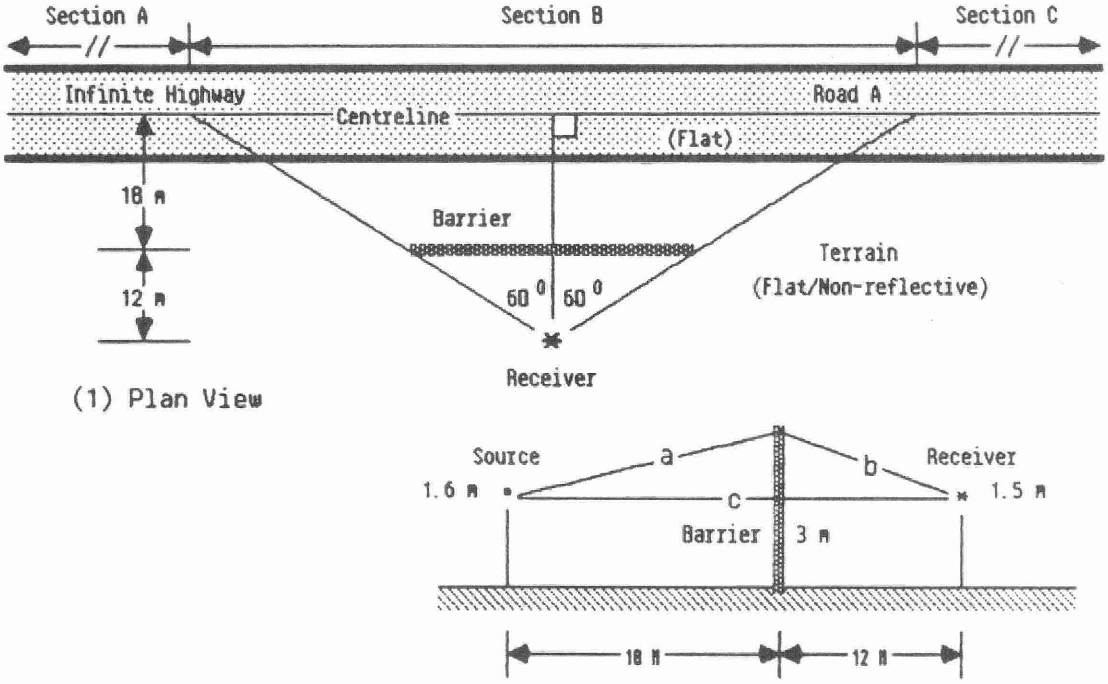
STEP 1. Since the traffic flow conditions and the characteristics of the road and of the surrounding terrain are uniform along the length of the highway under consideration, the road need not be divided into sections. Enter the appropriate lane designations for the two-lane highway on Line 1.

FIGURE 1

Conditions On Site



(A) Before Barrier



(1) Plan View

(2) Elevation View

(B) After Barrier

Vehicles Per Hour			Posted Speed (km/h)
Passenger Cars	Medium Trucks	Heavy Trucks	
910	20	70	80

(C) Traffic Data

FIGURE 2 Sample Calculation - Before Barrier

Name J. Smith Date May 5, 1986 File LU - 5001 Project Description Road A - Before Barrier

			Road A											
1	Lanes/Road Section (Element)		EB and WB											
2	Volume -Automobiles (vph)	S 2.2(a)	910											
3	Medium Trucks (vph)		20											
4	Heavy Trucks (vph)		70											
5	Total Volume (vph)		1000											
6	Posted Speed (km/h)		80											
7	Heavy Trucks (%)		7											
	Adjusted Heavy Trucks	S 2.2(b)												
8	Road Gradient (%)		0											
9	Adjustment Factor	Table 1												
10	Adjusted Volume (vph)													
11	Medium & Heavy Trucks (%)	S 2.2(c)	9											
12	Medium Trucks (%)	S 2.2(d)	22											
13	Reference Sound Level (dBA)	Tables 3-6		59										
	Effective Heights													
14	Source (s) (m)	Table 8	1.6											
15	Receiver (r) (m)		1.5											
16	Shielding (t+p) (m)	Table 7												
17	Total Effective Height (m)	Table 7	3.1											
	Adjustments													
18	Volume (dBA)	Table 2		14										
19	Distance (m)		30											
20	Reflective (dBA)	Table 7												
21	Non-reflective (dBA)	Table 7		-5										
22	Element, θ_1 (degrees)		-90											
23	θ_2 (degrees)		90											
24	Reflective (dBA)	Table 9												
25	Non-reflective (dBA)	Table 11		-1										
26	Pavement Surface (dBA)	Table 12		0										
27	Woods (dBA)	Table 13												
28	Rows Of Houses (dBA)	Table 13												
	Barrier Shielding													
29	θ_1 (degrees)													
30	θ_2 (degrees)													
31	Finite Barrier Index	Table B1												
32	Path Length Difference (m)	Table B2												
33	Barrier Attenuation (dBA)	Table B2												
34	Section Leq(h) (dBA)			67										
35	Road Leq(h) (dBA)	Table 14		67										

FIGURE 3 Sample Calculation - After Barrier

Name J. Smith Date May 5, 1986 File LU - 5001 Project Description Road A - After Barrier

			Section A				Section B				Section C			
1	Lanes/Road Section (Element)		EB and WB				EB and WB				EB and WB			
2	Volume -Automobiles (vph)	S 2.2(a)	910				910				910			
3	Medium Trucks (vph)		20				20				20			
4	Heavy Trucks (vph)		70				70				70			
5	Total Volume (vph)		1000				1000				1000			
6	Posted Speed (km/h)		80				80				80			
7	Heavy Trucks (%)		7				7				7			
	Adjusted Heavy Trucks	S 2.2(b)												
8	Road Gradient (%)		0				0				0			
9	Adjustment Factor	Table 1												
10	Adjusted Volume (vph)													
11	Medium & Heavy Trucks (%)	S 2.2(c)	9				9				9			
12	Medium Trucks (%)	S 2.2(d)	22				22				22			
13	Reference Sound Level (dBA)	Tables 3-6		59				59				59		
	Effective Heights													
14	Source (s) (m)	Table 8	1.6				1.6				1.6			
15	Receiver (r) (m)		1.5				1.5				1.5			
16	Shielding (t+p) (m)	Table 7					6							
17	Total Effective Height (m)	Table 7	3.1				9.1				3.1			
	Adjustments													
18	Volume (dBA)	Table 2		14				14				14		
19	Distance (m)		30				30				30			
20	Reflective (dBA)	Table 7												
21	Non-reflective (dBA)	Table 7		-5				-3				-5		
22	Element, θ_1 (degrees)		-90				-60				60			
23	θ_2 (degrees)		-60				60				90			
24	Reflective (dBA)	Table 9						-2						
25	Non-reflective (dBA)	Table 11		-11								-11		
26	Pavement Surface (dBA)	Table 12		0				0				0		
27	Woods (dBA)	Table 13												
28	Rows Of Houses (dBA)	Table 13												
	Barrier Shielding													
29	θ_1 (degrees)						-60							
30	θ_2 (degrees)						60							
31	Finite Barrier Index	Table B1					20							
32	Path Length Difference(m)	Table B2					.148							
33	Barrier Attenuation (dBA)	Table B2						-9						
34	Section Leq(h) (dBA)			57				59				57		
35	Road Leq(h) (dBA)	Table 14		62.5										

STEP 2. Complete Lines 2-6 and 8 from the data given in the problem statement. Complete Line 7. The heavy trucks are expressed as a percentage of total volume.

STEP 3. Determine the adjustment factor for heavy trucks on up-hill grades from Table 1. Enter the adjustment factor on Line 9 and the adjusted volume on Line 10. In the given sample calculation, the road gradient is 0% and no adjustment is required.

STEP 4. Calculate the percentage trucks (medium + heavy) (9%) as per section 2.2 (c) and enter on Line 11.

Calculate the percentage of medium trucks (22%) as per Section 2.2 (d) and enter on Line 12.

STEP 5. Determine the Reference Sound Level from Table 3, using the data shown on Lines 6, 11, and 12. Enter this reference level (59 dBA) on Line 13.

STEP 6. Determine the Effective Source Height (1.6 m) from Table 8 and enter on Line 14. Enter the Receiver Height (1.5 m) on Line 15. Enter the Total Effective Height (1.6 m + 1.5 m) on Line 17.

STEP 7. Determine the adjustment for volume from Table 2, using the volume of 1000 vehicles shown on Line 5. Enter this adjustment (14 dBA) on Line 18.

STEP 8. Complete Line 19 (30 m). Determine the adjustment for distance from the section of Table 7 for non-reflective surfaces using the data shown on Lines 17 and 19. Enter the adjustment (-5 dBA) on Line 21.

STEP 9. Refer to Table 10 and determine the angles ϕ_1 and ϕ_2. Enter $\phi_1 = -90°$ and $\phi_2 = +90°$ on Lines 22 and 23.

Determine the adjustment (-1 dBA) for road element size from Table 11 and enter on Line 25.

STEP 10. Determine the adjustment (0 dBA) for pavement surface type from Table 12 and enter on Line 26.

STEP 11. Calculate the resultant sound level, $L_{eq}(h)$ (67 dBA) and enter on Lines 34 and 35.

5.2 After Barrier Sound Level

STEP 1. As shown in Figure 1, due to the finite barrier, the highway must be divided into three sections. Refer to Table 10 and determine ϕ_1 and ϕ_2 for each section.

(i) Section A $\phi_1 = -90°$, $\phi_2 = -60°$
(ii) Section B $\phi_1 = -60°$, $\phi_2 = +60°$
(iii) Section C $\phi_1 = +60°$, $\phi_2 = +90°$

STEP 2. Enter the appropriate lane designations for Sections A, B and C on Line 1.

STEP 3. For each road section complete Lines 2-15. The entries are identical to those recorded in Section 5.1.

(i) Section A

STEP 1. Complete Lines 17-21 and 26. The entries are identical to those recorded in Section 5.1.

STEP 2. Enter $\phi_1 = -90°$ and $\phi_2 = -60°$ on Lines 22 and 23. Determine the adjustment (-11 dBA) for road element size from Table 11 and enter on Line 25.

STEP 3. Calculate the resultant sound level Leq(h) (57 dBA) and enter on Line 34.

(ii) Section B

STEP 1. Refer to Table 7 and enter the effective height of shielding ($t + p = 6$ m) on Line 16. Determine the Total Effective Height (9.1 m) and enter on Line 17.

STEP 2. Complete Lines 18, 19 and 26. The entries are identical to those recorded in Section 5.1.

STEP 3. Determine the adjustment (-3 dBA) for distance from Table 7 using the data shown on Lines 17 and 19. Enter the adjustment on Line 21.

STEP 4. Enter $\phi_1 = -60°$ and $\phi_2 = +60°$ on Lines 22 and 23. Determine the adjustment (-2 dBA) for road element size from Table 9 and enter on Line 24.

STEP 5. Enter $\phi_1 = 60°$ and $\phi_2 = +60°$ on Lines 29 and 30. Determine the Finite Barrier Index (20) from Table B1 and enter on Line 31.

Determine the Path Length Difference (0.148 m) using the figure and formula in Table B2 and enter on Line 32.

Determine the Barrier Attenuation (-9 dBA) from Table B2 and enter on Line 33.

STEP 6. Calculate the resultant sound level Leq(h) (59 dBA) and enter on Line 34.

(iii) Section C

STEP 1. Complete Lines 17-21 and 26. The entries are identical to those recorded in Section 5.1.

STEP 2. Enter ϕ_1 = +60° and ϕ_2 = +90° on Lines 22 and 23. Determine the adjustment (-11 dBA) for road element size from Table 11 and enter on Line 25.

STEP 3. Calculate the resultant sound level Leq(h) (57 dBA) and enter on Line 34.

(iv) Combined Sound Level

Calculate the combined Leq(h) (62.5 dBA) for road Sections A, B and C using the rule for addition of sound levels in Table 14. Enter the road L_{eq}(h) on Line 35.

5.3 Barrier Insertion Loss

The net reduction in the traffic sound level provided by a barrier is called the Barrier Insertion Loss (BIL), i.e.

BIL = Level (Before) - Level (After)

In this problem, the barrier insertion loss is 4.5 dBA (67 - 62.5).

Note: The barrier attenuation and the barrier insertion loss are identical only if (a) the barrier shields the entire roadway and (b) the ground surface between the source and the receiver is "sound reflective".

APPENDIX A

TRAFFIC NOISE PREDICTION TABLES

TABLE 1
Adjustment to Percentage of Heavy Trucks on Up-Hill Grades

Road Gradient %	Adjustment Factor (Multiplicative)
0 to less than 2	1
2 to less than 5	1.5
5 to less than 7	2
Over 7	3

TABLE 2
Adjustment to the Reference Hourly Sound Level for Traffic Volume

Use the nearest listed value when the actual value of volume is not listed.

Hourly Traffic Volume	Adjustment (Additive) dBA	Hourly Traffic Volume	Adjustment (Additive) dBA	Hourly Traffic Volume	Adjustment (Additive) dBA
40	0	315	9	2000	17
50	1	400	10	2500	18
63	2	500	11	3150	19
80	3	630	12	4000	20
100	4	800	13	5000	21
125	5	1000	14	6300	22
160	6	1250	15	8000	23
200	7	1600	16	10000	24
250	8				

Given the posted speed limit of traffic in km/h and the total percentage of trucks (including medium and heavy trucks), the following Tables 3 and 4 provide the predicted Reference Hourly Sound Level at 15 m from the centreline of a road section with a total traffic volume of 40 vehicles per hour (vph). Use the nearest listed value when the actual value of speed or truck percentage is not listed.

TABLE 3

Reference Hourly Sound Level in dBA at 15 m and 40 vph:
Percentage of Medium Trucks in the Range of 0 - 25 %.

POSTED SPEED km/h	PERCENTAGE TRUCKS (MEDIUM+HEAVY)													
	1	2	4	6	9	12	16	21	26	35	45	60	80	100
40	48	49	51	53	54	55	57	58	59	60	61	62	63	64
50	50	51	53	54	56	57	58	59	60	61	62	63	65	66
60	52	53	55	56	57	58	59	60	61	62	63	65	66	67
70	54	55	56	57	58	59	60	61	62	63	65	66	67	68
80	55	56	57	58	59	60	61	62	63	64	65	67	68	69
90	56	57	58	59	60	61	62	63	64	65	66	67	69	69
100	57	58	59	60	61	62	63	64	65	66	67	68	69	70

TABLE 4

Reference Hourly Sound Level in dBA at 15 m and 40 vph:
Percentage of Medium Trucks in the Range of 26 - 50 %.

POSTED SPEED km/h	PERCENTAGE TRUCKS (MEDIUM+HEAVY)													
	1	2	4	6	9	12	16	21	26	35	45	60	80	100
40	47	49	51	52	53	54	56	57	57	59	60	61	62	63
50	50	51	53	54	55	56	57	58	59	60	61	62	64	65
60	52	53	54	55	56	57	59	60	60	62	63	64	65	66
70	53	54	56	57	58	59	60	61	61	63	64	65	66	67
80	55	56	57	58	59	60	61	62	62	64	65	66	67	68
90	56	57	58	59	60	61	62	63	63	65	65	67	68	69
100	57	58	59	60	61	62	63	63	64	65	66	67	69	69

Given the posted speed limit of traffic in km/h and the total percentage of trucks (including medium and heavy trucks), the following Tables 5 and 6 provide the predicted Reference Hourly Sound Level at 15 m from the centreline of a road section with a total traffic volume of 40 vehicles per hour (vph). Use the nearest value when the actual value of speed or truck percentage is not listed.

TABLE 5

Reference Hourly Sound Level in dBA at 15 m and 40 vph: Percentage of Medium Trucks in the Range of 51 - 75 %.

POSTED SPEED km/h	PERCENTAGE TRUCKS (MEDIUM+HEAVY)													
	1	2	4	6	9	12	16	21	26	35	45	60	80	100
40	47	48	50	51	52	53	54	55	56	57	58	59	61	62
50	49	50	52	53	54	55	56	57	58	59	60	61	62	63
60	51	52	53	54	56	56	57	58	59	60	61	63	64	65
70	53	54	55	56	57	58	59	60	60	62	63	64	65	66
80	55	55	56	57	58	59	60	61	62	63	64	65	66	67
90	56	57	58	58	59	60	61	62	63	64	65	66	67	68
100	57	58	59	59	60	61	62	63	63	65	65	67	68	69

TABLE 6

Reference Hourly Sound Level in dBA at 15 m and 40 vph: Percentage of Medium Trucks in the Range of 76 - 100 %.

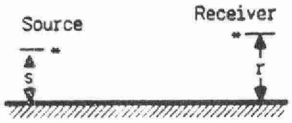
POSTED SPEED km/h	PERCENTAGE TRUCKS (MEDIUM+HEAVY)													
	1	2	4	6	9	12	16	21	26	35	45	60	80	100
40	46	47	48	49	50	51	52	53	54	55	56	57	58	59
50	49	50	51	52	53	53	54	55	56	57	58	59	60	61
60	51	52	53	53	54	55	56	57	58	59	60	61	62	63
70	53	53	54	55	56	57	58	58	59	60	61	62	63	64
80	54	55	56	56	57	58	59	60	60	61	62	64	65	66
90	56	56	57	58	59	59	60	61	62	63	64	65	66	67
100	57	57	58	59	60	60	61	62	63	64	65	66	67	68

TABLE 7

Adjustment for Distance from Centreline of Road to Point of Reception

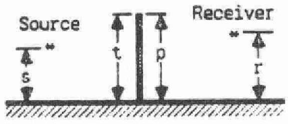
Total Effective Height (m)	Perpendicular Distance from Centreline of Road to Point of Reception (m)													
	10*	15	20	30	40	50	60	80	100	120	150	200	250	500
	Adjustment in dBA for Reflective Surfaces													
All Heights	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
Height	Adjustment in dBA for Non-Reflective Surfaces													
1.5	3	0	-2	-5	-6	-8	-9	-11	-12	-14	-15	-17	-18	-23
2	3	0	-2	-5	-6	-8	-9	-11	-12	-14	-15	-17	-18	-23
3	3	0	-2	-5	-6	-8	-9	-11	-12	-14	-15	-17	-18	-23
4	3	0	-2	-4	-6	-7	-9	-10	-12	-13	-14	-16	-17	-22
6	2	0	-2	-4	-5	-7	-8	-9	-11	-12	-13	-14	-16	-20
8	2	0	-1	-3	-5	-6	-7	-8	-9	-10	-11	-13	-14	-17
10	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
12	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
16	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
20	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
25	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
32	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
40	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
50	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
60	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15

NO BARRIER



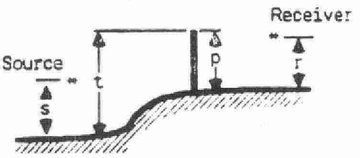
Effective Height=s+r

BARRIER



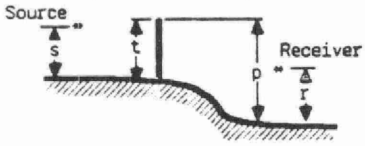
Effective Height=s+t+p+r

BARRIER (depressed road)



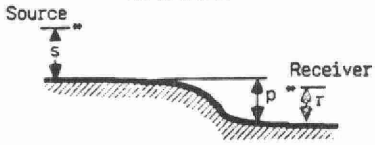
Effective Height=s+t+p+r

BARRIER (depressed site)



Effective Height=s+t+p+r

NO BARRIER



Effective Height=s+p+r

NO BARRIER

Effective Height=s+t+r

* Prediction accuracy decreases for distances less than 15 m from road centre.

TABLE 8

Effective Source Height of Road Traffic

Unadjusted Percentage of Heavy Trucks in Total Flow (%)	Effective Source Height (m)
0	0.5
1	1.0
2	1.2
3	1.3
4	1.4
5	1.5
6-7	1.6
8-9	1.7
10-11	1.8
12-14	1.9
15-17	2.0
18-21	2.1
22-25	2.2
26-30	2.3
>30	2.4

TABLE 9

Adjustment for Road Element Size: Reflective Surfaces

Subtended Angle ø (degrees)	Adjustment (dBA)	Subtended Angle ø (degrees)	Adjustment (dBA)
180	0	50	-6
160	-1	45	-6
140	-1	40	-7
120	-2	35	-7
100	-3	30	-8
90	-3	25	-9
80	-4	20	-10
70	-4	15	-11
60	-5	10	-13
55	-5	5	-16

TABLE 10

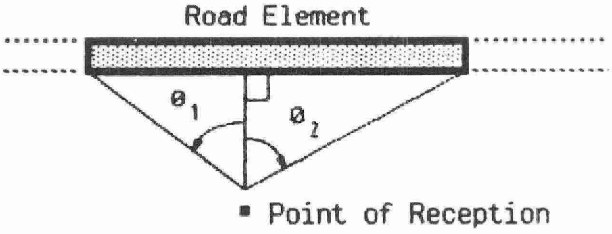
Angular Relationship between Road Elements and Receptor Locations

This table defines the angular relationship between a roadway element and a point of reception (observer) in terms of angles θ_1 and θ_2, expressed in degrees.

CASE 1

θ_1 is negative

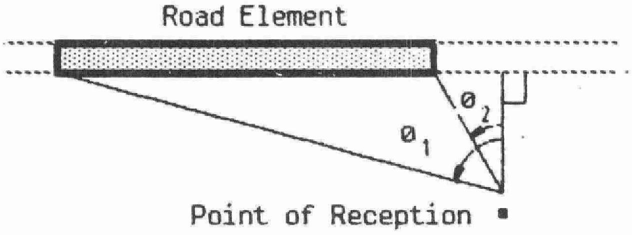
θ_2 is positive



CASE 2

θ_1 is negative

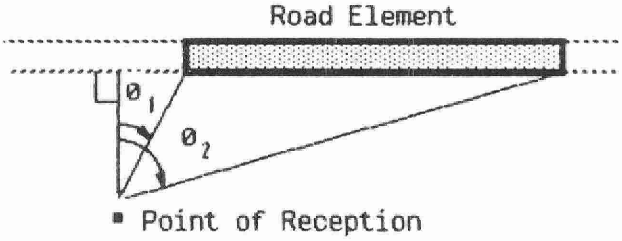
θ_2 is negative



CASE 3

θ_1 is positive

θ_2 is positive



SUBTENDED ANGLE of the road element at the point of reception:

$$\theta = \theta_2 - \theta_1$$

TABLE 11

Adjustment for Road Element Size: Non-Reflective Surfaces

	RIGHTMOST ROAD ANGLE, θ_2																		
LEFTMOST ROAD ANGLE, θ_1	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
	Adjustment in dBA																		
-90	-	-18	-14	-11	-9	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-1	-1	-1
-80	-	-	-16	-12	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2	-1	-1
-70	-	-	-	-14	-11	-9	-8	-6	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2	-1
-60	-	-	-	-	-14	-10	-9	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2	-2
-50	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2
-40	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3	-2	-2
-30	-	-	-	-	-	-	-	13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3	-3
-20	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-4	-3	-3
-10	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-4	-4
0	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-5	-4	-4
10	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-6	-5	-5
20	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-6	-6
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-9	-8	-7	-7
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-9	-8	-8
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14	-11	-10	-9
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14	-12	-11
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-16	-14
80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-18
90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 12

Adjustment for Pavement Surface Type

Pavement Surface Type	Adjustment (dBA)
Typical asphalt pavement such as HL-1	0
Open-graded friction course	-2.5
Dense-graded friction course	-1.5
Smooth concrete pavement	-1
* New concrete pavement, wire brush finish	+6
* Grooved concrete pavement	+7

* Not used on new highways

TABLE 13

Adjustment for Dense Woods and Rows of Houses

DENSE WOODS	
Depth of Woods between Source and Receiver (m)	Attenuation (dBA)
30	5
60	10
NOTE: Maximum attenuation allowed is 10 dBA	
FIRST ROW OF HOUSES	
Percentage of Row Occupied by Houses	Attenuation (dBA)
<40	0
40-65	3
65-90	5
>90	that of a barrier
ADDITIONAL ROWS OF HOUSES	
Apply attenuation of 1.5 dBA for each successive row up to a maximum of 10 dBA.	

TABLE 14

Addition of Sound Levels

Difference Between Higher and Lower Sound Levels (dBA)	To Obtain the Sum of Two Sound Levels, Add this Value to the Higher Level (dBA)
0	3.0
0.5	3.0
1.0	2.5
1.5	2.5
2.0	2.0
2.5	2.0
3.0	2.0
4.0	1.5
5.0	1.0
6.0	1.0
7.0	1.0
8.0	1.0
9.0	0.5
10.0	0
11.0	0
12.0	0
13.0 and up	0

APPENDIX B
CALCULATION OF BARRIER ATTENUATION

A "barrier" is any solid obstacle, natural or man made which interrupts the line of sight between the observer and the roadway.

Barriers include such items as elevated/depressed sections of roadway, large buildings, solid rows of townhouses, existing topographical features, earth berms, walls and fences. All of these obstructions may reduce noise generated by road traffic.

The following procedure is used to determine the attenuation of traffic noise provided by barriers of all types. This attenuation is commonly referred to as "barrier attenuation". The barrier is assumed to be parallel to the roadway and to obstruct the observer's view of the road. Calculations for finite and infinite length barriers are contained within this procedure.

STEP 1. Determine Barrier Extent

Determine ϕ_1 (the leftmost end angle of the barrier) and ϕ_2 (the rightmost end angle of the barrier). For Example, for infinite barriers ϕ_1 is -90° and ϕ_2 is +90.

STEP 2. Determine Finite Barrier Index

Determine the Finite Barrier Index (FBI) from Table B1, using the values of ϕ_1 and ϕ_2.

For example, FBI is 9 for an infinitely long barrier.

STEP 3. Determine Path Length Difference

Determine the Path Length Difference (PLD), according to the figure and formula shown in Table B2.

It must be noted that 'D_{SB}' and 'D_{BR}' are horizontal distances; therefore, the sum of D_{SB} and D_{BR} shall not be necessarily equal to the actual source-receiver separation distance.

Path Length Difference shall be calculated to an accuracy of at least 0.001 metres.

STEP 4. Obtain Barrier Attenuation

Determine the appropriate barrier attenuation* from Table B2, using the values of PLD and FBI.

---

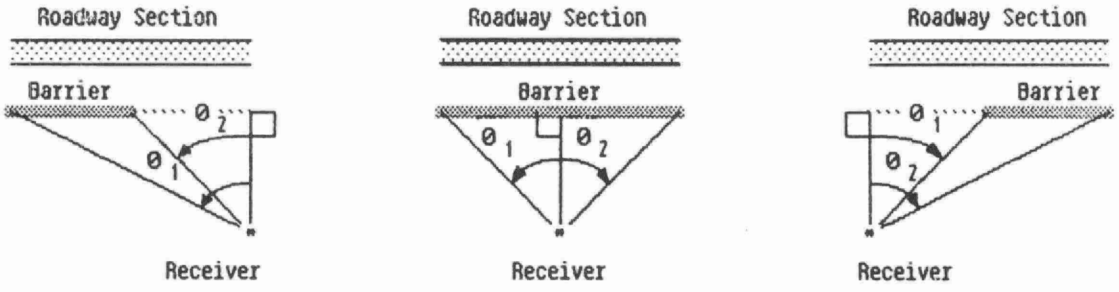
* The calculated barrier attenuation is accurate to ± 1.0 dBA, usually on the conservative side. The error in the barrier attenuation obtained from the table can be as high as 4 dBA for large values of PLD and acute angles of the barrier element. Such cases are: PLD greater than 4.0 m, $\phi_2-\phi_1$ less than 30° and ϕ_1 less than -70° or ϕ_2 more than +80°. In these circumstances the barrier attenuation could be under predicted by as much as 4 dBA. Nevertheless, this error has no appreciable influence on the overall result as the contributions from the remaining road elements dominate the resultant traffic noise level at the receiver.

TABLE B1

Finite Barrier Index for Asymmetric Barriers

θ_1, The Leftmost End Angle of the Barrier (degrees)	θ_2, The Rightmost End Angle of the Barrier (degrees)																	
	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
-90	1	2	3	4	6	7	9	9	9	10	12	12	12	12	14	12	12	9
-80	-	5	8	10	10	14	15	15	18	18	19	19	19	19	19	19	18	12
-70	-	-	10	11	15	15	18	19	19	19	19	19	19	19	19	19	19	12
-60	-	-	-	15	18	15	19	19	20	20	20	20	20	20	20	19	19	14
-50	-	-	-	-	19	20	20	20	21	21	23	23	21	21	20	19	19	12
-40	-	-	-	-	-	20	21	23	23	23	23	23	23	21	20	19	19	12
-30	-	-	-	-	-	-	23	23	23	23	23	23	23	23	20	19	19	12
-20	-	-	-	-	-	-	-	23	23	23	23	23	23	23	20	19	19	12
-10	-	-	-	-	-	-	-	-	24	24	23	23	23	21	20	19	18	10
0	-	-	-	-	-	-	-	-	-	24	23	23	23	21	20	19	18	9
10	-	-	-	-	-	-	-	-	-	-	23	23	23	20	19	19	15	9
20	-	-	-	-	-	-	-	-	-	-	-	23	21	20	19	18	15	9
30	-	-	-	-	-	-	-	-	-	-	-	-	20	20	19	15	14	7
40	-	-	-	-	-	-	-	-	-	-	-	-	-	19	18	15	10	6
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	11	10	4
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	8	3
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	2
80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

Angular Relationship between Barrier Sections and the Receiver



θ_1 is negative
θ_2 is negative

θ_1 is negative
θ_2 is positive

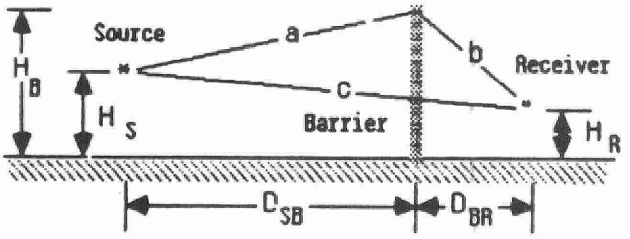
θ_1 is positive
θ_2 is positive

NOTES: 1) Where angles are not found in the table use the nearest listed value.

TABLE B2

Barrier Attenuation for Various Values of Finite Barrier Index

	Path Length Difference (m)	Finite Barrier Index																			
		1	2	3	4	5	6	7	8	9	10	11	12	14	15	18	19	20	21	23	24
		Barrier Attenuation (dBA)																			
Barrier does not interrupt the line of sight	0.34	3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.17	4	3	2	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
	0.07	5	4	4	4	4	3	3	3	2	2	2	1	1	1	1	1	1	1	0	0
	0.05	5	5	4	4	4	4	4	4	3	3	3	3	3	3	3	3	2	2	2	1
	0.03	5	5	5	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3
	0.02	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	0.00	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Barrier Does Interrupt the Line of Sight	0.03	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	7
	0.10	5	6	6	6	6	7	7	7	7	7	7	7	7	8	8	8	8	8	9	9
	0.17	6	6	7	7	7	7	7	7	8	8	8	8	8	9	9	9	9	10	10	11
	0.24	6	6	7	7	7	8	8	8	9	9	9	9	9	9	10	10	10	11	11	12
	0.28	6	7	8	8	8	9	9	9	9	9	9	10	10	10	10	11	11	12	12	12
	0.34	6	7	8	8	8	9	9	9	10	10	10	10	10	11	11	12	12	13	13	13
	0.52	7	8	8	9	9	10	10	10	11	11	12	12	12	12	13	13	14	14	14	15
	0.69	7	8	9	10	10	10	11	11	12	12	13	13	13	13	14	14	15	15	16	16
	1.03	8	9	10	11	12	12	12	13	13	14	14	14	15	15	15	16	17	17	18	18
	1.38	9	10	11	12	13	13	13	14	14	15	15	15	16	16	17	17	18	18	19	19
	1.70	9	11	12	13	14	14	14	15	15	16	16	16	17	17	18	18	19	19	20	20
	2.06	10	11	13	14	14	14	15	16	16	16	16	16	17	18	18	19	20	20	20	20
	2.75	11	13	14	15	15	15	16	16	16	17	17	17	18	19	19	19	20	20	20	20
	3.44	11	13	14	15	16	16	16	17	17	18	18	18	18	19	19	20	20	20	20	20
	5.16	12	14	15	16	17	17	17	18	18	18	18	18	19	20	20	20	20	20	20	20
	6.88	13	15	16	17	17	18	18	18	18	19	19	19	19	20	20	20	20	20	20	20



Barrier, Source and Receiver Configuration

PLD = a + b - c

Where

$$a = \sqrt{D_{SB}^2 + (H_B - H_S)^2}$$

$$b = \sqrt{D_{BR}^2 + (H_B - H_R)^2}$$

$$c = \sqrt{(D_{SB} + D_{BR})^2 + (H_S - H_R)^2}$$

NOTE: 1) Where the calculated PLD is not found in the table use the nearest listed value.

APPENDIX C

COMPUTATION OF $L_{EQ}(T)$

(BASED ON DAILY TRAFFIC VOLUMES)

In the planning of noise sensitive developments or of projects such as roads or industries, dependent on the application, traffic sound levels must be determined: (a) over a 24-hour period; (b) over a day or night time period or (c) on an hourly basis.

In many cases, the provincial/municipal traffic department may not be able to provide traffic data based on surveys conducted over specific time periods of the 24-hour day.

The following describes the method which may be used to determine the equivalent sound level, L_{eq}, due to road traffic over various time periods of the 24-hour day using the information on average daily traffic provided by the road authority.

1. Information Requirements

The road authority should be contacted for the following data:

(a) Average Annual Daily Traffic Volume (AADT) and when available the Summer Average Daily Traffic Volume (SADT); use the higher of AADT or SADT;

(b) Composition of traffic, i.e. the percentage of vehicles classified by the model as automobiles, medium trucks and heavy trucks; and

(c) Posted Speed Limit (km/h)

Future traffic volumes should be based on traffic projections at least 10 years after completion of the project or the ultimate capacity indicated by the road authority.

2. Method of Calculation

2.1 Method 1: Through Adjustments made to Existing/Future Traffic Volumes

Since the model predicts the equivalent sound level, L_{eq}, due to road traffic over a 1-hour time period, the average daily traffic volume (higher of AADT or SADT) must be reduced to a one-hour volume for the time period considered.

The following one-hour traffic volumes (existing/future) must be employed in calculating:

(a) Daily Sound Level (24-hours)

$$\text{volume (1 hr)} = \frac{\text{avg. daily volume}}{24}$$

(b) Daytime Sound Level (07:00 to 23:00)

$$\text{volume (1 hr)} = \frac{\text{avg. daily volume}}{16} \times T_D$$

Where: T_D = fraction of daily volume during daytime period

(c) Night-time Sound Level (23:00 to 7:00)

$$\text{volume (1 hr)} = \frac{\text{avg. daily volume}}{8} \times T_N$$

Where: T_N = fraction of daily volume during nighttime period

(d) Hourly Sound Level

$$\text{volume (1 hr)} = \frac{\text{avg. daily volume}}{1} \times T_H$$

Where: T_H = fraction of daily volume during a one hour period

When determining the traffic sound levels over various periods of the 24-hour day, the user must, of course, employ the estimated percentage of cars, medium trucks and heavy trucks which occur during the period under consideration.

2.2 Method 2: Through Adjustments made to Sound Levels - L_{eq} (24 hr)

This method may be used to determine the equivalent sound level, L_{eq}, due to road traffic over different time periods provided the traffic composition during the period under consideration does not vary greatly from the composition averaged over the entire 24-hour day.

(1) Adjustment for Period of Day

Once the existing/future traffic sound level, L_{eq} (24 hr), has been determined the following expression may be used to obtain:

(a) L_{eq} (16 hr) = Daytime Sound Level

$$L_{eq}\ (16\ hr) = L_{eq}\ (24\ hr) + 10\ \mathrm{Log}\ (24/16) + 10\ \mathrm{Log}\ (x)$$

(b) L_{eq} (8 hr) - Nighttime Sound Level

$$L_{eq}\ (8\ hr) = L_{eq}\ (24\ hr) + 10\ \mathrm{Log}\ (24/8) + 10\ \mathrm{Log}\ (x)$$

(c) L_{eq} (1 hr) - Hourly Sound Level

$$L_{eq}\ (1\ hr) = L_{eq}\ (24\ hr) + 10\ \mathrm{Log}\ (24) + 10\ \mathrm{Log}\ (x)$$

In the above expressions,

x = fraction of daily volume during the period considered

(2) Adjustments for Future Sound Levels

The future sound level, $L_{eq}(T)$, for any time period T of the 24-hour day may be obtained through application of an adjustment (in decibels) to the existing sound level.

The future sound level is given by the expression:

$$L_{eq}(T)_F = L_{eq}(T)_E + 10 \text{ Log } (1 + R)^N$$

Where:

R = Annual rate of change in traffic volume (a fraction)

N = Projected time period (in years)

The above method for determining future sound levels may be used only if there is no significant difference between the fraction of the existing daily traffic volume and that of the future daily traffic volume for the period of the 24-hour day under consideration.

3. Examples of Typical Variations in Traffic Sound Levels During the Day and Night Time Period

(a) Arterial Roads

On most arterial roads the major portion of the daily (24 hour) traffic volume, about 90%, tends to occur during the daytime period (07:00 to 23:00).

The following expressions indicate the approximate relationships between the equivalent sound levels over the day/night time periods and the 24-hour equivalent sound level.

$$L_{eq} \text{ (16 hr)} = L_{eq} \text{ (24 hr)} + 1 \qquad \text{(day)}$$

$$L_{eq} \text{ (8 hr)} = L_{eq} \text{ (24 hr)} - 5 \qquad \text{(night)}$$

(b) Highways

The typical split between traffic volumes during the day and night time periods on highways is about 85% (day) and 15% (night).

The equivalent sound levels for these respective time periods are given by:

$$L_{eq}\ (16\ \text{hr}) = L_{eq}\ (24\ \text{hr}) + 1 \qquad \text{(day)}$$

$$L_{eq}\ (8\ \text{hr}) = L_{eq}\ (24\ \text{hr}) - 3.5 \qquad \text{(night)}$$

(c) Freeways (Controlled Access)

On sites adjacent to most freeways no significant differences are considered between the equivalent sound levels measured over the 16 hour daytime and 8 hour nighttime periods.

APPENDIX D
TRAFFIC NOISE
PREDICTION WORK SHEET

TRAFFIC NOISE PREDICTION WORK SHEET

Name ____________ Date ____________ File ____________ Project Description ______________________________

1	Lanes/Road Section (Element)													
2	Volume -Automobiles (vph)	§ 2.2(a)												
3	Medium Trucks (vph)													
4	Heavy Trucks (vph)													
5	Total Volume (vph)													
6	Posted Speed (km/h)													
7	Heavy Trucks (%)													
	Adjusted Heavy Trucks	§ 2.2(b)												
8	Road Gradient (%)													
9	Adjustment Factor	Table 1												
10	Adjusted Volume (vph)													
11	Medium & Heavy Trucks (%)	§ 2.2(c)												
12	Medium Trucks (%)	§ 2.2(d)												
13	Reference Sound Level (dBA)	Tables 3-6												
	Effective Heights													
14	Source (s) (m)	Table 8												
15	Receiver (r) (m)													
16	Shielding (t+p) (m)	Table 7												
17	Total Effective Height (m)	Table 7												
	Adjustments													
18	Volume (dBA)	Table 2												
19	Distance (m)													
20	Reflective (dBA)	Table 7												
21	Non-reflective (dBA)	Table 7												
22	Element, θ_1 ______ (degrees)													
23	θ_2 ______ (degrees)													
24	Reflective (dBA)	Table 9												
25	Non-reflective (dBA)	Table 11												
26	Pavement Surface (dBA)	Table 12												
27	Woods (dBA)	Table 13												
28	Rows Of Houses (dBA)	Table 13												
	Barrier Shielding													
29	θ_1 ______ (degrees)													
30	θ_2 ______ (degrees)													
31	Finite Barrier Index	Table B1												
32	Path Length Difference(m)	Table B2												
33	Barrier Attenuation (dBA)	Table B2												
34	Section Leq(h) (dBA)													
35	Road Leq(h) (dBA)	Table 14												

APPENDIX B

GUIDELINES FOR RAIL TRAFFIC NOISE ASSESSMENT

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GUIDELINES
FOR
RAILWAY TRAFFIC NOISE ASSESSMENT

ONTARIO MINISTRY OF THE ENVIRONMENT
ENVIRONMENTAL APPROVALS AND LAND USE PLANNING BRANCH
DECEMBER 1986

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1.0 INTRODUCTION

1.1 General

The impact of train noise is an important factor to be considered when assessing land use compatibility. This document is an instruction manual that contains the MOE's recommended train traffic noise prediction procedure used in land use planning. Specifically, it presents the calculation procedure that yields the energy equivalent sound level, Leq, at a point of reception.

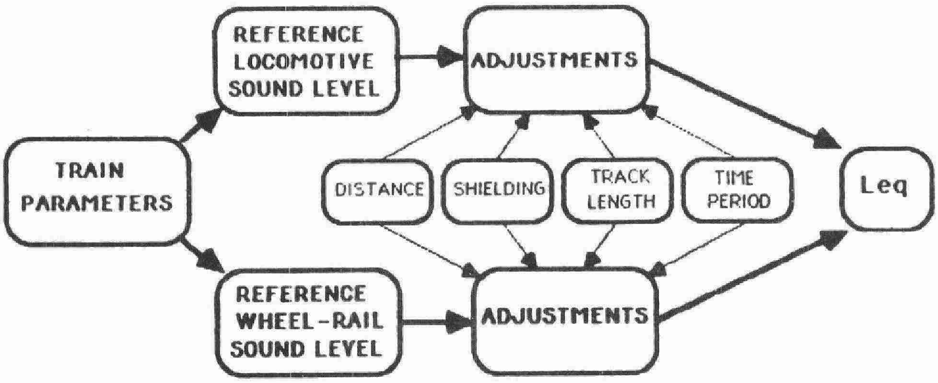
The prediction method is based on a model contained in the Canada Mortgage and Housing Corporation (CMHC) manual "Road and Rail Noise: Effect on Housing, 1981". The adjustments to the reference level for distance and shielding are defined identically to those contained in the MOE publication "Guidelines for Road Traffic Noise Assessment, July 1986".

The first part of this manual describes the prediction procedure: Section 2 describes the required parameters, Section 3 contains step-by-step instructions and Section 4 presents the limitations of the prediction model in terms of distance and topography. The final section, Section 5, contains a sample calculation performed utilizing a standard train traffic noise prediction worksheet.

The second part of this manual contains a set of appendices: Appendix A contains all the prediction tables used in the calculation, Appendix B describes the barrier attenuation calculation, Appendix C contains all the relevant mathematical expressions, Appendix D contains a procedural flowchart and Appendix E contains a train noise prediction worksheet.

1.2 Block Diagram

The following block diagram is used to describe the calculation procedure for the energy equivalent sound level for a given time period at a point of reception. The full procedural flowchart is presented in Appendix D.



2.0 PARAMETERS

2.1 Source/Receiver Characteristics

The train noise prediction model assumes the source of noise to be a line source that may be infinite or finite depending on the extent of the track that affects the point of reception (receiver). The basic sound level calculation, at a 15 m reference distance, is performed for an infinite line source on a reflective ground using a reference operating speed and a number of cars and

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locomotives during a 24-hour period. Subsequently, appropriate adjustments for distance, finite track length, shielding and for the time period are made.

(a) Traffic Parameters

The train traffic parameters consisting of the traffic volume, speed, number of locomotives per train and the number of cars per train are essential to the calculation.

(b) Time Period

In order to comply with the MOE's land use compatibility guidelines, the sound levels must be calculated for the day-time 16-hour period, 07:00-23:00, and the night-time 8-hour period, 23:00-07:00. If only 24-hour traffic information is available, estimates of the day-time/night-time traffic volume must be used.

(c) Noise Source

Train noise is produced by the engine of a locomotive and by the train wheels and their interaction with the rail; whistle noise is not considered in this manual. For calculation purposes, the locomotive noise source is considered to be 4 m above ground (rail track) and the wheel-rail noise source is considered to be 0.5 m above the track.

(d) Receiver

For the outdoor noise level calculation, the receiver height is considered to be 1.5 m above ground. For

the night-time noise impact prediction, the receiver is normally assumed to be a second storey bedroom window, located 4.5 m above ground.

(e) Separation Distance

The distance between the point of reception and the center line of the train track is the shortest line joining the point of reception to the center of the train track.

(f) Length of Track

The length of the track is defined by the angles subtended at the point of reception and by the separation distance. An infinite track length is defined by -90° and 90°.

(g) Total Effective Height

The total effective height is determined by adding together the appropriate source height, the receiver height and the effective height of shielding (see Table 4).

(h) Reference Sound Level

The reference sound level is a level at a reference distance of 15 m from the centre line of the track.

3.2 Topography

(a) Ground Cover

(i) Reflective Surface

Water, ice, asphalt, gravel, earth or other hard-packed surfaces are sound reflective.

If more than half of the ground surface between the centre line of the train track and the point of reception is sound reflective, the ground surface is considered reflective.

(ii) Other Surfaces (Non-Reflective)

If less then half of the ground surface between the centre line of the train track and the point of reception is sound reflective, the ground surface is considered non-reflective. A non-relfective surface affects sound propagation so that distance attenuation may be greater than 3 dB per doubling of distance.

(b) Shielding (Obstructions)

The type of shielding can be divided into the following three categories:

(i) barrier
(ii) rows of houses
(iii) dense woods

3.0 CALCULATION PROCEDURE

The following contains a detailed calculation procedure for the prediction of a combined Leq produced by the locomotive engine noise and the wheel-rail noise. The calculation is for a 24-hour, a 16-hour and an 8-hour period.

3.1 Identification of Train Types

(a) Terminology

The traffic volume on the track must be separated into specific train types such as passenger, freight, switcher, etc. The terminology of the identification has been chosen only for convenience; the prediction model distinguishes between train types according to following Clause (b).

(b) Definition

A train type shall be defined by the following variables, i.e. the variables must be approximately constant:

- train speed
- number of locomotives per train
- number of cars per train

3.2 Locomotive Sound Level

The following calculation procedure for the prediction of noise produced by the locomotive engine must be repeated for all train types.

(a) Reference Sound Level

The reference locomotive sound level is the level at 15 m from the centre line of the track. It is determined from Table 1, which gives the sound level for a train speed of 80 km/h, and from Table 2, which gives the adjustment for the actual speed.

The above calculation steps must be repeated for all train types and the resultant sound levels combined using the

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rule for addition of sound levels in Table 9. The resultant level is the overall reference locomotive sound level.

(b) Adjustment for Distance

Table 4 shall be used to adjust for distance and for the type of ground surface between the point of reception and the centre line of the train track. The adjustment shall be added to the reference sound level.

(c) Adjustment for Barrier Shielding

Tables B1 and B2 shall be used to adjust the resultant sound level produced by all train types for barrier attentuation. The adjustment is additive.

If the barrier is finite, the track must be divided into sections defined by the angles subtended at the point of reception (see Tables 8 and B1).

3.3 Wheel-Rail Sound Level

The following calculation procedure must be repeated for all train types.

(a) Reference Sound Level

The reference wheel-rail sound level at 15 m from the centre line of the track shall be determined using Table 3.

The above calculation steps must be repeated for all train types and the resultant sound levels combined using the rule for addition of sound levels in Table 9. The

resultant level is the overall reference wheel-rail sound level.

(b) Adjustment for Distance

Table 4 shall be used to adjust for distance and for the type of ground surface between the point of reception and the centre line of the train track. The adjustment shall be added to the reference sound level.

(c) Adjustment for Barrier Shielding

Tables B1 and B2 shall be used to adjust the resultant sound level produced by all train types for barrier attentuation. The adjustment is additive.

If the barrier is finite, the track must be divided into sections defined by the angles subtended at the point of reception (see Tables 8 and B1).

3.4 Combined Sound Level

The resultant adjusted sound levels obtained in sub-sections 3.2 and 3.3, representing the locomotive and the wheel-rail contributions, must be combined using the rule for addition of sound levels in Table 9. The energy equivalent sound level, Leq, at the point of reception is then obtained by performing the adjustments in the following clauses (a), (b) and (c).

(a) Adjustment for Ground Surface and Track Length

An adjustment must be added to the sound level if the ground surface is non-reflective or if the track length

considered in the calculation is not infinite. The value of the adjustment is given in Tables 6 and 7, for reflective and non-reflective surfaces respectively.

If the track was divided into sections due to the presence of a finite barrier, the contributions from each section must be combined using the rule for addition of sound levels in Table 9.

(b) Adjustment for Shielding by Housing and Woods

(i) Dense Woods*

An adjustment for the attenuation by woods shall be made if, and only if, the woods are very dense, i.e. that is no visual path between the receiver and the track (may not hold for deciduous trees in winter), and if the trees extend at least 5 m above the line of site. Table 5 gives the adjustment for shielding provided by dense woods; the adjustment is additive.

(ii) Rows of Houses*

Table 5 gives the adjustment for shielding provided by rows of houses; the adjustment is additive.

---

*When a receiver is shielded by dense woods or rows of houses, the ground surface must be considered "reflective".

(iii) Combined Shielding Adjustment

The combined attenuation of dense woods and rows of houses is additive up to a maximum of 10 dBA. Furthermore, the total adjustment due to attenuation produced by barriers, dense woods and rows of houses, i.e. 3.2(c) and 3.4(b), or 3.3(c) and 3.4(b), is limited to a maximum of 20 dBA.

(c) Time Period Adjustment

If the calculation is for 8-hour or 16-hour periods, but the sound level values in Tables 1 and 3 have been used, a time period adjustment must be added. The value of this adjustment is:

- 2 dBA for the 16-hour period and
- 5 dBA for the 8-hour period

4.0 LIMITATIONS

The method for prediction of train traffic noise described herein is not applicable when the distance from the point of reception to the centre line of the train track is less than 10 m.

In addition, the prediction accuracy may decrease where:

(a) The topography is very irregular (eg. many different intervening man-made or natural obstructions of substantial elevations in ground cover);

(b) The distance from the point of reception to the centre line of the train track is less than 15 m.

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5.0 TRAIN NOISE CALCULATION WORK SHEET

This section contains a train noise calculation work sheet and examples of calculations.

5.1 Work Sheet

A work sheet is enclosed as Appendix E. The work sheet is divided into three parts. Parts A and B contain locomotive and wheel-rail calculations, respectively. Included in Parts A and B are distance and sound barrier (acoustic fence and earth berm) shielding adjustments. Part C contains the combined locomotive and wheel-rail Leq calculation, and adjustments for shielding due to dense woods and rows of houses, track length and time period.

The general procedure on how to use the work sheet is detailed below:

PART A - LOCOMOTIVE NOISE

Step 1 - Traffic Data

1. Enter the appropriate traffic information on lines 1 to 6.

2. Complete lines 7 to 9 from the data given on lines 3 to 5.

Step 2 - Overall Reference Leq

1. Determine the sound level, Leq, at 15 m from the track and for train speed of 80 km/h from Table 1, using the data shown on lines 8 and 9.

2. Enter the sound level, Leq, on line 10.

3. Determine the speed adjustment from Table 2 and enter on line 11.

4. Calculate the reference Leq at 15 m and enter on line 12.

5. Repeat the above (1 to 4) for each train type.

6. Calculate the overall reference Leq (all train types) and enter on line 13.

Step 3 - Distance Adjustment

1. Enter the distance from the source to the receiver on line 14.

2. Determine the source height, receiver height and effective height of shielding on lines 15, 16 and 17.

3. Enter the total effective height on line 18.

4. Determine the distance adjustment from Table 4, using the data shown on lines 14 and 18, and enter on line 19.

Step 4 - Barrier Shielding

1. Refer to Table 8, determine and enter the angles ϕ_1 and ϕ_2 on lines 20 and 21.

2. Determine the finite barrier index from Table B1 and enter on line 22.

3. Determine the path length difference using the figure and formula in Table B2 and enter on line 23.

4. Determine the barrier attenuation from Table B2 and enter on line 24.

Step 5 - Locomotive Leq

2. Determine the locomotive Leq adjusted for distance and barrier shielding and enter on line 25.

PART B - WHEEL-RAIL NOISE

Step 6 - Traffic Data

1. Copy lines 2, 6 and 7 onto lines 26, 27 and 28 respectively.

Step 7 - Overall Reference Leq

1. Determine the reference Leq at 15 m from the track from Table 3, using the data shown on lines 27 and 28.

2. Enter the reference Leq on line 29.

3. Repeat the above (1 and 2) for each train type.

4. Calculate the overall reference Leq (all train types) and enter on line 30.

Step 8 - Distance Adjustment

1. Enter the distance from the source to the receiver on line 31.

2. Determine the source height, receiver height and effective height of shielding on lines 32, 33 and 34.

3. Enter the total effective height on line 35.

4. Determine the distance adjustment from Table 4 using the data shown on lines 31 and 35 and enter on line 36.

Step 9 - Barrier Shielding

1. Refer to Table 8, determine and enter the angles ϕ_1 and ϕ_2 on lines 37 and 38.

2. Determine the finite barrier index from Table B1 and enter on line 39.

3. Determine the path length difference using the figure and formula in Table B2 and enter on line 40.

4. Determine the barrier attenuation from Table B2 and enter on line 41.

Step 10 - Wheel-Rail Leq

1. Determine the wheel-rail Leq adjusted for distance and barrier shielding and enter on line 42.

PART C

Step 11 - Locomotive and Wheel-Rail Leq Before Adjustment

1. Determine the locomotive and wheel-rail Leq from Table 9 using the data shown on lines 25 and 42 and enter on line 43.

Step 12 - Adjustment

1. Determine the dense woods shielding adjustment from Table 5 and enter on line 44.

2. Determine the rows of houses shielding adjustment from Table 5 and enter on line 45.

3. Determine the track length adjustment from Table 6 or 7 and enter on line 48 or 49.

4. Determine the time period adjustment and enter on line 50.

Step 13 - Locomotive and Wheel-Rail Leq After Adjustment

1. Determine the locomotive and wheel-rail Leq adjusted for dense woods shielding, rows of houses shielding, track length and time period and enter on line 50.

2. Repeat the above procedure for as many sections of the track as required.

3. Determine the overall Leq for all sections of track and enter on line 52.

5.2 **Examples of Calculation**

This section contains examples of calculations of the equivalent sound level, Leq(h), generated by train traffic. The calculations were performed through the use of tables and noise prediction work sheets.

Problems

Refer to Figure 1. Using the information provided, determine the daytime equivalent sound levels, Leq, at the

receiver due to train traffic on the track before and after barrier construction.

The train track is flat (no gradient), infinitely long. The track and the surrounding terrain are at the same grade; the ground is non-reflective. The receiver is located 30 m from the centre line of the track and 1.5 m above ground. The barrier is located 10 m from the receiver, 5 m high and finite as shown in Figure 1. There are three types of trains, freights, passenger and transfer.

Solution

The train traffic sound levels before and after the barrier is constructed have been calculated on separate work sheets. Refer to Figures 2 to 4.

Figure 2 shows the calculation for before barrier construction.

Figures 3 and 4 show the calculations for after barrier construction for train track Sections A and B, respectively.

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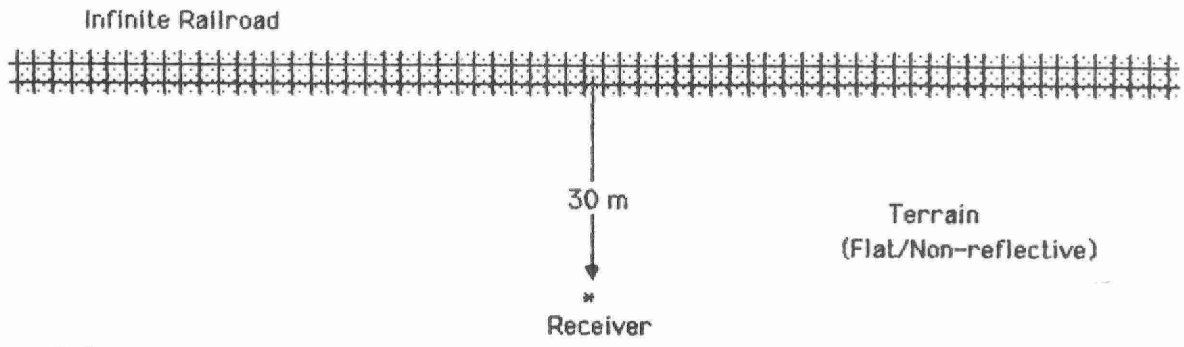
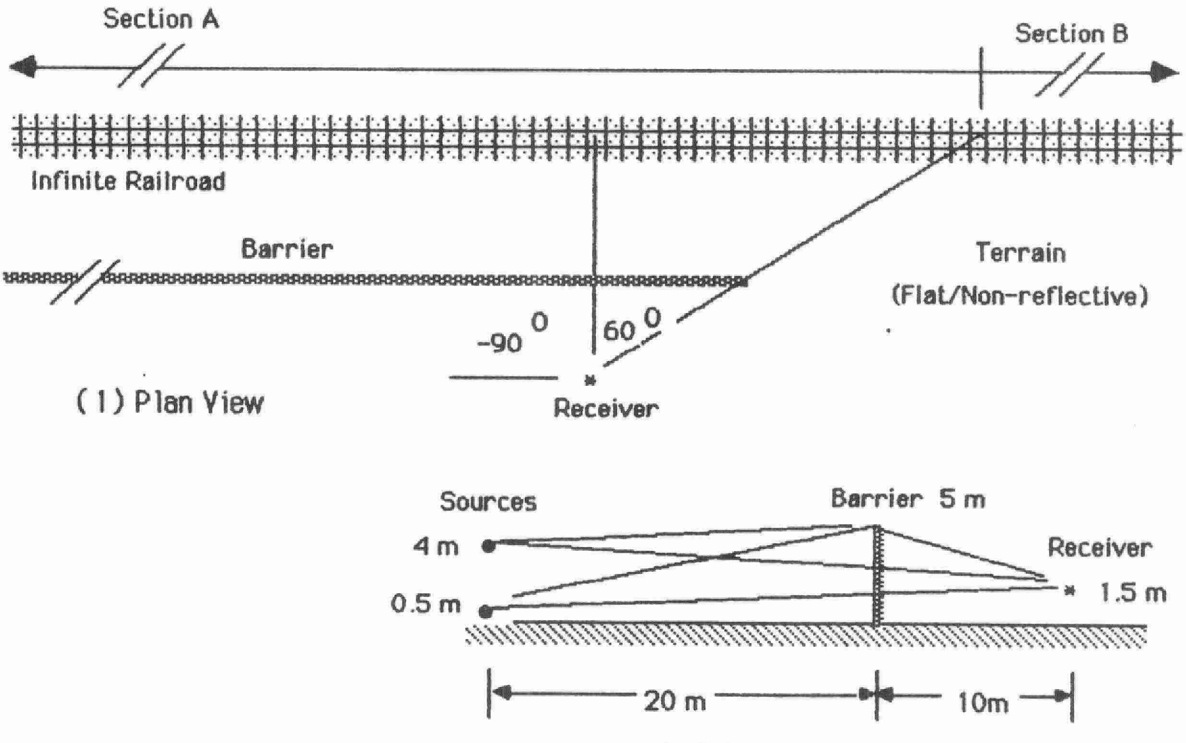
FIGURE 1

Conditions On Site



(A) Before Barrier



(B) After Barrier

Time Period	Train Type	No. of Trains	No. of Cars	No. of Locomotives	Speed (km/h)
700 to 2300 hours	Freight	17	90	3	80
	Passenger	6	10	1	90
	Transfer	7	30	1	80

(C) Traffic Data

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FIGURE 2

TRAIN NOISE WORK SHEET

Name________ Date Dec 9, 86 File Sample Description Before Barrier

PART A - LOCOMOTIVE NOISE

1	Time Period		700 to 2300 hours							
2	Train Type		Freight		Passenger		Transfer			
3	No. of Trains		17		6		7			
4	No. of Locomotives/Train		3		1		1			
5	No. of Cars/Train		90		10		30			
6	Typical Train Speed (km/h)		80		90		80			
7	Total No. of Cars		1530		60		210			
8	Total No. of Locomotives		51		6		7			
9	Average No. of Cars /Loco		30		10		30			
10	L eq @ 15m & 80 km/h (dBA)	Table 1		68		56		60		
11	Speed Adjustment (dBA)	Table 2		0		1		0		
12	Reference Leq (dBA)			68		57		60		
13	Overall Reference Leq (dBA)	Table 9		69						
14	Distance (m)		30							
	Effective Height									
15	Source (s) (m)		4							
16	Receiver (r) (m)		1.5							
17	Shielding (t+p) (m)									
18	Total Effective Height (m)		5.5							
19	Distance Adjustment (dBA)	Table 4		-4						
	Barrier Shielding		N/A							
20	Ø 1 (degree)									
21	Ø 2 (degree)									
22	Finite Barrier Index	Table B1								
23	Path Length Difference (m)	Table B2								
24	Barrier Attenuation (dBA)	Table B2								
25	Locomotive Leq (dBA)			65						

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TRAIN NOISE WORK SHEET

Description Before Barrier

PART B - WHEEL-RAIL NOISE

26	Train Type		Freight		Passenger		Transfer			
27	Typical Train Speed (km/h)		80		90		80			
28	Total No. of Cars		1530		60		210			
29	Reference Leq @ 15m (dBA)	Table 3		67		54		58		
30	Overall Reference Leq (dBA)	Table 9		68						
31	Distance (m)		30							
	Effective Height									
32	Source (s) (m)		0.5							
33	Receiver (r) (m)		1.5							
34	Shielding (t+p) (m)									
35	Total Effective Height (m)		2.0							
36	Distance Adjustment (dBA)	Table 4		-5						
	Barrier Shielding									
37	Ø 1 (degree)		N/A							
38	Ø 2 (degree)									
39	Finite Barrier Index	Table B1								
40	Path Length Difference (m)	Table B2								
41	Barrier Attenuation (dBA)	Table B2								
42	Wheel-Rail Leq (dBA)			63						

PART C

43	Loco &Wheel-Rail Leq (dBA)	Table 9		67
	Adjustment			
44	Dense Woods (dBA)	Table 5		
45	Rows of Houses (dBA)	Table 5		
	Track Length			
46	Ø 1 (degree)		-90	
47	Ø 2 (degree)		+90	
48	Reflective (dBA)	Table 6		
49	Non-reflective (dBA)	Table 7		-1
50	Time Period (dBA)			+2
51	Loco &Wheel-Rail Leq (dBA)		68	
52	Overall Leq (dBA)		68	

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FIGURE 3

TRAIN NOISE WORK SHEET

Name________ Date Dec 9, 86 File Sample Description After Barrier - Section A

PART A - LOCOMOTIVE NOISE

1	Time Period		700 to 2300 hours							
2	Train Type		Freight		Passenger		Transfer			
3	No. of Trains		17		6		7			
4	No. of Locomotives/Train		3		1		1			
5	No. of Cars/Train		90		10		30			
6	Typical Train Speed (km/h)		80		90		80			
7	Total No. of Cars		1530		60		210			
8	Total No. of Locomotives		51		6		7			
9	Average No. of Cars /Loco		30		10		30			
10	L eq @ 15m & 80 km/h (dBA)	Table 1		68		56		60		
11	Speed Adjustment (dBA)	Table 2		0		1		0		
12	Reference Leq (dBA)			68		57		60		
13	Overall Reference Leq (dBA)	Table 9		69						
14	Distance (m)		30							
	Effective Height									
15	Source (s) (m)		4							
16	Receiver (r) (m)		1.5							
17	Shielding (t+p) (m)		10							
18	Total Effective Height (m)		15.5							
19	Distance Adjustment (dBA)	Table 4		-3						
	Barrier Shielding									
20	Ø 1 (degree)		-90							
21	Ø 2 (degree)		+60							
22	Finite Barrier Index	Table B1	14							
23	Path Length Difference (m)	Table B2	0.52							
24	Barrier Attenuation (dBA)	Table B2		-12						
25	Locomotive Leq (dBA)			54						

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TRAIN NOISE WORK SHEET

Description After Barrier - Section A

PART B - WHEEL-RAIL NOISE

26	Train Type		Freight		Passenger		Transfer			
27	Typical Train Speed (km/h)		80		90		80			
28	Total No. of Cars		1530		60		210			
29	Reference Leq @ 15m (dBA)	Table 3		67		54		58		
30	Overall Reference Leq (dBA)	Table 9		68						
31	Distance (m)		30							
	Effective Height									
32	Source (s) (m)		0.5							
33	Receiver (r) (m)		1.5							
34	Shielding (t+p) (m)		10							
35	Total Effective Height (m)		12							
36	Distance Adjustment (dBA)	Table 4		-3						
	Barrier Shielding									
37	θ 1 (degree)		-90							
38	θ 2 (degree)		+60							
39	Finite Barrier Index	Table B1	14							
40	Path Length Difference (m)	Table B2	1.08							
41	Barrier Attenuation (dBA)	Table B2		-15						
42	Wheel-Rail Leq (dBA)			50						

PART C

43	Loco &Wheel-Rail Leq (dBA)	Table 9		55.5
	Adjustment			
44	Dense Woods (dBA)	Table 5		
45	Rows of Houses (dBA)	Table 5		
	Track Length			
46	θ 1 (degree)		-90	
47	θ 2 (degree)		+60	
48	Reflective (dBA)	Table 6		-1
49	Non-reflective (dBA)	Table 7		
50	Time Period (dBA)			+2
51	Loco &Wheel-Rail Leq (dBA)		56.5	
52	Overall Leq (dBA)			

FIGURE 4

TRAIN NOISE WORK SHEET

Name__________ Date Dec 9, 86 File Sample Description After Barrier - Section B

PART A - LOCOMOTIVE NOISE

1	Time Period		700 to 2300 hours							
2	Train Type		Freight		Passenger		Transfer			
3	No. of Trains		17		6		7			
4	No. of Locomotives/Train		3		1		1			
5	No. of Cars/Train		90		10		30			
6	Typical Train Speed (km/h)		80		90		80			
7	Total No. of Cars		1530		60		210			
8	Total No. of Locomotives		51		6		7			
9	Average No. of Cars /Loco		30		10		30			
10	L eq @ 15m & 80 km/h (dBA)	Table 1		68		56		60		
11	Speed Adjustment (dBA)	Table 2		0		1		0		
12	Reference Leq (dBA)			68		57		60		
13	Overall Reference Leq (dBA)	Table 9		69						
14	Distance (m)		30							
	Effective Height									
15	Source (s) (m)		4							
16	Receiver (r) (m)		1.5							
17	Shielding (t+p) (m)									
18	Total Effective Height (m)		5.5							
19	Distance Adjustment (dBA)	Table 4		-4						
	Barrier Shielding		N/A							
20	Ø 1 (degree)									
21	Ø 2 (degree)									
22	Finite Barrier Index	Table B1								
23	Path Length Difference (m)	Table B2								
24	Barrier Attenuation (dBA)	Table B2								
25	Locomotive Leq (dBA)			65						

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TRAIN NOISE WORK SHEET

Description After Barrier - Section B

PART B - WHEEL-RAIL NOISE

26	Train Type		Freight		Passenger		Transfer			
27	Typical Train Speed (km/h)		80		90		80			
28	Total No. of Cars		1530		60		210			
29	Reference Leq @ 15m (dBA)	Table 3		67		54		58		
30	Overall Reference Leq (dBA)	Table 9		68						
31	Distance (m)		30							
	Effective Height									
32	Source (s) (m)		0.5							
33	Receiver (r) (m)		1.5							
34	Shielding (t+p) (m)									
35	Total Effective Height (m)		2.0							
36	Distance Adjustment (dBA)	Table 4		-5						
	Barrier Shielding		N/A							
37	Ø 1 (degree)									
38	Ø 2 (degree)									
39	Finite Barrier Index	Table B1								
40	Path Length Difference (m)	Table B2								
41	Barrier Attenuation (dBA)	Table B2								
42	Wheel-Rail Leq (dBA)			63						

PART C

43	Loco &Wheel-Rail Leq (dBA)	Table 9		67
	Adjustment			
44	Dense Woods (dBA)	Table 5		
45	Rows of Houses (dBA)	Table 5		
	Track Length			
46	Ø 1 (degree)		+60	
47	Ø 2 (degree)		+90	
48	Reflective (dBA)	Table 6		
49	Non-reflective (dBA)	Table 7		-11
50	Time Period (dBA)			+ 2
51	Loco &Wheel-Rail Leq (dBA)		58	
52	Overall Leq (dBA)		60.5	

APPENDIX A: PREDICTION TABLES

TABLE 1

Locomotive noise level in dBA at 15 m from the track for train speed of 80 km/h
(Based on 24-hour traffic volume)

Total number of locomotives	**Average number of cars per locomotive**							
	1-4	5-11	12-18	19-26	26-32	33-39	40-46	47-53
≤ 4	53	54	55	56	57	58	59	60
5	54	55	56	57	58	59	60	61
6	55	56	57	58	59	60	61	62
7-8	56	57	58	59	60	61	62	63
9-10	57	58	59	60	61	62	63	64
11-13	58	59	60	61	62	63	64	65
14-17	59	60	61	62	63	64	65	66
18-22	60	61	62	63	64	65	66	67
23-28	61	62	63	64	65	66	67	68
29-35	62	63	64	65	66	67	68	69
36-45	63	64	65	66	67	68	69	70
46-56	64	65	66	67	68	69	70	71
57-71	65	66	67	68	69	70	71	72
72-90	66	67	68	69	70	71	72	73
91-110	67	68	69	70	71	72	73	74
111-142	68	69	70	71	72	73	74	75
143-180	69	70	71	72	73	74	75	76
181-225	70	71	72	73	74	75	76	77

TABLE 2

Adjustment to Locomotive Noise for Actual Train Speed

Actual train speed (km/h)	0-34	35-43	44-51	52-61	62-74	75-86	87-105	>105
Adjustment (dBA)	-5	-4	-3	-2	-1	0	1	2

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TABLE 3

Wheel-rail noise level in dBA at 15 m from the track
(Based on 24-hour traffic volume)

Total number of railway cars	**Train speed (km/h)**												
	up to 27	28 to 29	30 to 34	35 to 40	41 to 47	48 to 53	54 to 61	62 to 72	73 to 84	85 to 98	98 to 111	112 to 129	over 129
up to 70	45	46	47	48	49	50	51	52	53	54	55	56	57
71 - 90	46	47	48	49	50	51	52	53	54	55	56	57	58
91 - 110	47	48	49	50	51	52	53	54	55	56	57	58	59
111 - 140	48	49	50	51	52	53	54	55	56	57	58	59	60
141 - 180	49	50	51	52	53	54	55	56	57	58	59	60	61
181 - 220	50	51	52	53	54	55	56	57	58	59	60	61	62
221 - 280	51	52	53	54	55	56	57	58	59	60	61	62	63
281 - 350	52	53	54	55	56	57	58	59	60	61	62	63	64
351- 440	53	54	55	56	57	58	59	60	61	62	63	64	65
441 - 560	54	55	56	57	58	59	60	61	62	63	64	65	66
561 - 700	55	56	57	58	59	60	61	62	63	64	65	66	67
701 - 890	56	57	58	59	60	61	62	63	64	65	66	67	68
891 - 1120	57	58	59	60	61	62	63	64	65	66	67	68	69
1121 - 1400	58	59	60	61	62	63	64	65	66	67	68	69	70
1401 - 1770	59	60	61	62	63	64	65	66	67	68	69	70	71
1771 - 2230	60	61	62	63	64	65	66	67	68	69	70	71	72
2231 - 2800	61	62	63	64	65	66	67	68	69	70	71	72	73

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TABLE 4

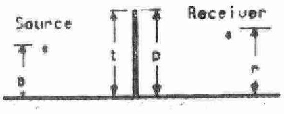
Adjustment for Distance from Centre Line of Track to Point of Reception

Total Effective Height (m)	Perpendicular Distance from Centreline of Track to Point of Reception (m)													
	10*	15	20	30	40	50	60	80	100	120	150	200	250	500
	Adjustment in dBA for Reflective Surfaces													
All Heights	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
Height	**Adjustment in dBA for Non-Reflective Surfaces**													
1.5	3	0	-2	-5	-6	-8	-9	-11	-12	-14	-15	-17	-18	-23
2	3	0	-2	-5	-6	-8	-9	-11	-12	-14	-15	-17	-18	-23
3	3	0	-2	-5	-6	-8	-9	-11	-12	-14	-15	-17	-18	-23
4	3	0	-2	-4	-6	-7	-9	-10	-12	-13	-14	-16	-17	-22
6	2	0	-2	-4	-5	-7	-8	-9	-11	-12	-13	-14	-16	-20
8	2	0	-1	-3	-5	-6	-7	-8	-9	-10	-11	-13	-14	-17
10	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
12	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
16	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
20	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
25	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
32	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
40	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
50	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15
60	2	0	-1	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-15

NO BARRIER

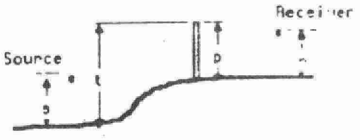
Effective Height=s+r

BARRIER



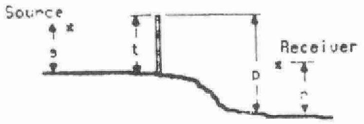
Effective Height=s+t+p+r

BARRIER (depressed track)



Effective Height=s+t+p+r

BARRIER (depressed site)



Effective Height=s+t+p+r

NO BARRIER

Effective Height=s+p+r

NO BARRIER

Effective Height=s+t+r

*** Prediction accuracy decreases for distances less than 15 m from track centre.**

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TABLE 5

Adjustment for Dense Woods and Rows of Houses

DENSE WOODS	
Depth of Woods between Source and Receiver (m)	**Attenuation (dBA)**
30 60	5 10
NOTE: Maximum attenuation allowed is 10 dBA	
FIRST ROW OF HOUSES	
Percentage of Row Occupied by Houses	**Attenuation (dBA)**
<40	0
40-65	3
65-90	5
>90	that of a barrier
ADDITIONAL ROWS OF HOUSES	
Apply attenuation of 1.5 dBA for each successive row up to a maximum of 10 dBA.	

TABLE 6

Adjustment for Track Element Size: Reflective Surfaces

Subtended Angle ø (degrees)	Adjustment (dBA)	Subtended Angle ø (degrees)	Adjustment (dBA)
180	0	50	-6
160	-1	45	-6
140	-1	40	-7
120	-2	35	-7
100	-3	30	-8
90	-3	25	-9
80	-4	20	-10
70	-4	15	-11
60	-5	10	-13
55	-5	5	-16

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TABLE 7

Adjustment for Track Length: Non-Reflective Surfaces

RIGHTMOST TRACK ANGLE, θ2

Adjustment in dBA

LEFTMOST ANGLE, θ1	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
-90	-	-18	-14	-11	-9	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-1	-1	-1
-80	-	-	-16	-12	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2	-1	-1
-70	-	-	-	-14	-11	-9	-8	-6	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2	-1
-60	-	-	-	-	-14	-10	-9	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2	-2
-50	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2
-40	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3	-2	-2
-30	-	-	-	-	-	-	-	13	-10	-8	-7	-6	-5	-4	-4	-3	-3	-3	-3
-20	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-4	-3	-3
-10	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-4	-4	-4	-4
0	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-5	-5	-4	-4
10	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-6	-5	-5
20	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-8	-7	-6	-6	-6
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-9	-8	-7	-7
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-13	-10	-9	-8	-8
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14	-11	-10	-9
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-14	-12	-11
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-16	-14
80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-18
90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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TABLE 8

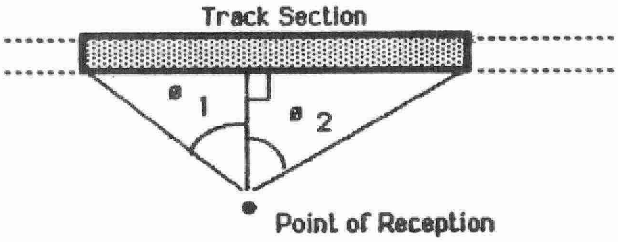
Angular Relationship between Track Sections and Receptor Locations

This table defines the angular relationship between a track section and a point of reception (receiver) in terms of angles ϕ_1 and ϕ_2 .

CASE 1

ϕ_1 is negative

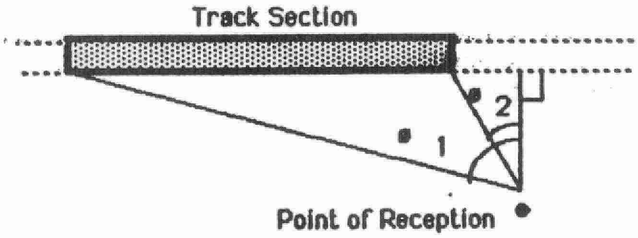
ϕ_2 is positive



CASE 2

ϕ_1 is negative

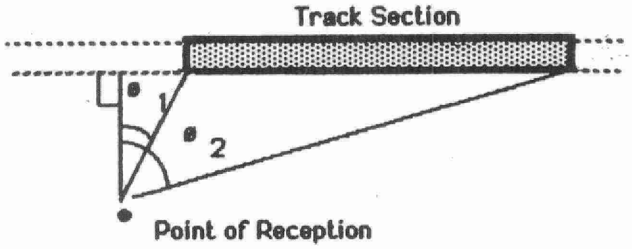
ϕ_2 is negative



CASE 3

ϕ_1 is positive

ϕ_2 is positive



SUBTENDED ANGLE of the track section at the point of reception:

$$\phi = \phi_2 - \phi_1$$

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TABLE 9

Addition of Sound Levels

Difference Between Higher and Lower Sound Levels (dBA)	To Obtain the Sum of Two Sound Levels, Add this Value to the Higher Level (dBA)
0	3.0
0.5	3.0
1.0	2.5
1.5	2.5
2.0	2.0
2.5	2.0
3.0	2.0
4.0	1.5
5.0	1.0
6.0	1.0
7.0	1.0
8.0	1.0
9.0	0.5
10.0	0
11.0	0
12.0	0
13.0 and up	0

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APPENDIX B

CALCULATION OF BARRIER ATTENUATION

A "barrier" is any solid obstacle, natural or man made which interrupts the line of sight between the observer and the railway.

Barriers include such items as elevated/depressed sections of railway, large buildings, solid rows of townhouses, existing topographical features, earth berms, walls and fences. All of these obstructions may reduce noise generated by rail traffic.

The following procedure is used to determine the attenuation of rail traffic noise provided by barriers of all types. This attenuation is commonly referred to as "barrier attenuation". The barrier is assumed to be parallel to the railway traffic and to obstruct the observer's view of the track. Calculations for finite and infinite length barriers are contained within this procedure.

STEP 1. Determine Barrier Extent

Determine ϕ_1 (the leftmost end angle of the barrier) and ϕ_2 (the rightmost end angle of the barrier). For Example, for infinite barriers ϕ_1 is -90° and ϕ_2 is +90.

STEP 2. Determine Finite Barrier Index

Determine the Finite Barrier Index (FBI) from Table B1, using the values of ϕ_1 and ϕ_2.

For example, FBI is 9 for an infinitely long barrier.

STEP 3. Determine Path Length Difference

Determine the Path Length Difference (PLD), according to the figure and formula shown in Table B2.

It must be noted that 'D_{SB}' and 'D_{BR}' are horizontal distances; therefore, the sum of D_{SB} and D_{BR} shall not be necessarily equal to the actual source-receiver separation distance.

Path Length Difference shall be calculated to an accuracy of at least 0.001 metres.

STEP 4. Obtain Barrier Attenuation

Determine the appropriate barrier attenuation* from Table B2, using the values of PLD and FBI.

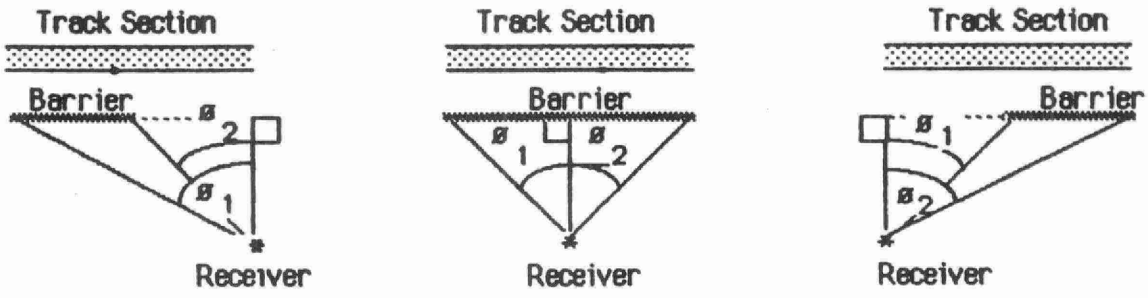
* (The calculated barrier attenuation is accurate to ± 1.0 dBA, usually on the conservative side). The error in the barrier attenuation obtained from the table can be as high as 4 dBA for large values of PLD and acute angles of the finite barrier. Such cases are: PLD greater than 4.0 m, $\phi_2-\phi_1$ less than 30° and ϕ_1 less than -70° or ϕ_2 more than +80°. In these circumstances the barrier attenuation could be under predicted by as much as 4 dBA. Nevertheless, this error has no appreciable influence on the overall result as the contributions from the remaining track sections dominate the resultant traffic noise level at the receiver.

TABLE B1

Finite Barrier Index for Asymmetric Barriers

	ϕ_2 , The Rightmost End Angle of the Barrier (degrees)																	
ϕ_1 , The Leftmost End Angle of ther Barrier (degrees)	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
-90	1	2	3	4	6	7	9	9	9	10	12	12	12	12	14	12	12	9
-80	-	5	8	10	10	14	15	15	18	18	19	19	19	19	19	19	18	12
-70	-	-	10	11	15	15	18	19	19	19	19	19	19	19	19	19	19	12
-60	-	-	-	15	18	19	19	19	20	20	20	20	20	20	20	19	19	14
-50	-	-	-	-	19	20	20	20	21	21	23	23	21	21	20	19	19	12
-40	-	-	-	-	-	20	21	23	23	23	23	23	23	21	20	19	19	12
-30	-	-	-	-	-	-	23	23	23	23	23	23	23	23	20	19	19	12
-20	-	-	-	-	-	-	-	23	23	23	23	23	23	23	20	19	19	12
-10	-	-	-	-	-	-	-	-	24	24	23	23	23	21	20	19	18	10
0	-	-	-	-	-	-	-	-	-	24	23	23	23	21	20	19	18	9
10	-	-	-	-	-	-	-	-	-	-	23	23	23	20	19	19	15	9
20	-	-	-	-	-	-	-	-	-	-	-	23	21	20	19	18	15	9
30	-	-	-	-	-	-	-	-	-	-	-	-	20	20	19	15	14	7
40	-	-	-	-	-	-	-	-	-	-	-	-	-	19	18	15	10	6
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	11	10	4
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	8	3
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	2
80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

Angular Relationship between Barrier Sections and the Receiver



ϕ_1 is negative
ϕ_2 is negative

ϕ_1 is negative
ϕ_2 is positive

ϕ_1 is positive
ϕ_2 is positive

Notes: 1) Where angles are not found in the table use the nearest listed value

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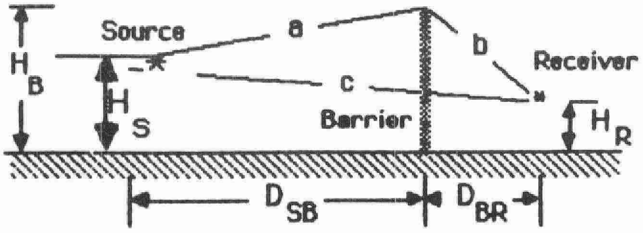
TABLE B2

Barrier Attenuation for Various Values of Finite Barrier Index

	Path Length Difference (m)	Finite Barier Index																			
		1	2	3	4	5	6	7	8	9	10	11	12	14	15	18	19	20	21	23	24
		Barrier Attenuation (dBA)																			
Barrier does not interrup the line of sight	0.34	3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.17	4	3	2	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
	0.07	5	4	4	4	4	3	3	3	2	2	2	1	1	1	1	1	1	1	0	0
	0.05	5	5	4	4	4	4	4	4	3	3	3	3	3	3	3	3	2	2	2	1
	0.03	5	5	5	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3
	0.02	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	0.00	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Barrier Does Interrupt the Line of Sight	0.03	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	7
	0.10	5	6	6	6	6	7	7	7	7	7	7	7	7	8	8	8	8	8	9	9
	0.17	6	6	7	7	7	7	7	7	8	8	8	8	8	9	9	9	9	10	10	11
	0.24	6	6	7	7	7	8	8	8	9	9	9	9	9	9	10	10	10	11	11	12
	0.28	6	7	8	8	8	9	9	9	9	9	9	10	10	10	10	11	11	12	12	12
	0.34	6	7	8	8	8	9	9	9	10	10	10	10	10	11	11	12	12	13	13	13
	0.52	7	8	8	9	9	10	10	10	11	11	12	12	12	12	13	13	14	14	14	15
	0.69	7	8	9	10	10	10	11	11	12	12	13	13	13	13	14	14	15	15	16	16
	1.03	8	9	10	11	12	12	12	13	13	14	14	14	15	15	15	16	17	17	18	18
	1.38	9	10	11	12	13	13	13	14	14	15	15	15	16	16	17	17	18	18	19	19
	1.70	9	11	12	13	14	14	14	15	15	16	16	16	17	17	18	18	19	19	20	20
	2.06	10	11	13	14	14	14	15	16	16	16	16	16	17	18	18	19	20	20	20	20
	2.75	11	13	14	15	15	15	16	16	16	17	17	17	18	19	19	19	20	20	20	20
	3.44	11	13	14	15	16	16	16	17	17	18	18	18	18	19	19	20	20	20	20	20
	5.16	12	14	15	16	17	17	17	18	18	18	18	18	19	20	20	20	20	20	20	20
	6.88	13	15	16	17	17	18	18	18	18	19	19	19	19	20	20	20	20	20	20	20



Barrier, Source and Receiver Configuration

PLD = a + b − c

Where

$$a = \sqrt{D_{SB}^2 + (H_B - H_S)^2}$$

$$b = \sqrt{D_{BR}^2 + (H_B - H_R)^2}$$

$$c = \sqrt{(D_{SB} + D_{BR})^2 + (H_S - H_R)^2}$$

NOTE : 1) Where the calculated PLD is not found in the table use the nearest listed value.

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APPENDIX C: MATHEMATICAL DESCRIPTION

The noise emitted during passby of a railway train consists of two main components: locomotive engine and exhaust noise; and wheel-rail interaction noise. Whistle noise is not considered part of the general train passby noise.

The mathematical expressions governing the above two types of noise are defined in the following sections. Included are also the expressions defining all the various adjustments required to complete the calculation for the energy equivalent sound level, Leq, at a point of reception. The mathematical expressions described in this appendix have been used to generate the prediction tables contained in Appendix A. As the values shown in the tables have been rounded off to the nearest decibel, calculations performed using the following expressions yield more accurate results.

C.1. Locomotive Exhaust Noise

The energy equivalent sound level produced by the locomotive engine and exhaust noise is given by:

$$\begin{aligned} L_{eq,L} &= 10 \log N - 10 \log S + 0.15x + 55 + \Delta_{tot}, & S < 30 \text{ km/h} \\ &= 10 \log N + 13.5 \log S + 0.15x + 22 + \Delta_{tot}, & S > 30 \text{ km/h} \end{aligned}$$

where N is the total number of locomotives in a 24-hour period,
x is the number of cars per locomotive,
S is the operating speed,
and Δ_{tot} is the total adjustment for locomotive noise (section C.3.).

C.2. Wheel-rail Interaction Noise

The energy equivalent sound level produced by the wheel-rail interaction noise is given by:

$$L_{eq,W} = 5.3 + 10 \log n + 15.7 \log S + \Delta_{tot}$$

where n is the number of railway cars in a 24-hour period
and Δ_{tot} is total adjustment for wheel-rail noise (section C.3.).

C.3. Adjustments

C.3.1. Distance adjustment

For distances other than the reference distance of 15 m from the centre line of the track, an adjustment must be added. The distance adjustment is given by:

$$\Delta_{dist} = 10 \log (D_0/D)^{1+\alpha}$$

where D_0 is the reference distance of 15 m from track centre line,
D is the perpendicular distance from the centre line of the track to the point of reception,
and α is the ground absorption coefficient defined by:

$$\begin{aligned} \alpha &= 0.5\,, && h \leq 3\text{ m} \\ &= 0.715\,(1 - h/10)\,, && 3\text{ m} < h < 10\text{ m} \\ &= 0\,, && h \geq 10\text{ m} \end{aligned}$$

C.3.2. Track length and ground surface adjustment

When the ground is is non-reflective or when the calculation considers a finite section of the track, an adjustment must be added. The value of the adjustment is given by:

$$\begin{aligned} \Delta_{track} &= 10 \log \{(1/\pi) \int_{\phi_1}^{\phi_2} \sqrt{\cos \phi}\; d\phi\}, && \text{for non-reflective surfaces} \\ &= 10 \log \{(\phi_2 - \phi_1)/\pi\}, && \text{for reflective surfaces} \end{aligned}$$

where ϕ_1 and ϕ_2 are the angles subtended by the track section at the point of reception, see Table 8.

C.3.3. Adjustment for shielding by dense woods and rows of houses

An adjustment Δ_{wh} must added to account for shielding of dense woods or rows of houses. This adjustment is described in section 3.4 (b) of the main document.

C.3.4. Barrier adjustment

The barrier adjustment accounts for barrier attenuation. Although it is recognised that the dominant frequency of the wheel-rail noise is higher than that of the locomotive noise, the barrier attenuation expressions and the resultant attenuation values assume a frequency of 500 Hz. This seemingly conflicting assumption is reconciled by the adoption of substantially different source heights, 0.5 m for the wheel-rail noise and 4 m for the locomotive noise. The barrier attenuation, further described in Appendix B, is given by:

$$\Delta_{barr} = 10 \log \left\{ 1/(\phi_2 - \phi_1) \int_{\phi_1}^{\phi_2} 10^{-\Delta/10} \, d\phi \right\}$$

where ϕ_1 and ϕ_2 are the subtended angles,

and Δ is a point source attenuation given by:

$$\Delta = 0 \qquad N \leq -0.1916$$

$$= 5 + 20 \log \left\{ \frac{\sqrt{2\pi |N_0| \cos \phi}}{\tan \sqrt{2\pi |N_0| \cos \phi}} \right\} \qquad -0.1916 < N \leq 0$$

$$= 5 + 20 \log \left\{ \frac{\sqrt{2\pi (N_0) \cos \phi}}{\tanh \sqrt{2\pi (N_0) \cos \phi}} \right\} \qquad 0 < N \leq 5.03$$

$$= 20 \qquad N > 5.03$$

where $N = N_0 \cos \phi$,

and N_0 is the Fresnel number at 500 Hz, $N_0 = (2/\lambda)\,\mathrm{PLD} = 2.915\,(\mathrm{PLD})$,

where PLD is the path length difference along the perpendicular.

C.3.5. Time period adjustment

The sound level calculation must be adjusted for the time period to which the train traffic volume is applicable. This adjustment is given by:

$$\Delta_{time} = 10 \log (T_{ref}/T)$$

where T_{ref} is a 24-hour period

and T is the relevant time period, such as 8-hour or 16-hour.

C.4. References

R. E. Halliwell and J. D. Quirt, "Traffic Noise Prediction", Building Research Note 146, National Research Council of Canada, Division of Building Research, Ottawa, March 1980.

Canada Mortgage and Housing Corporation, "Road and Rail Noise: Effects on Housing", Cat. No. NHA 5156 81/10, 1981.

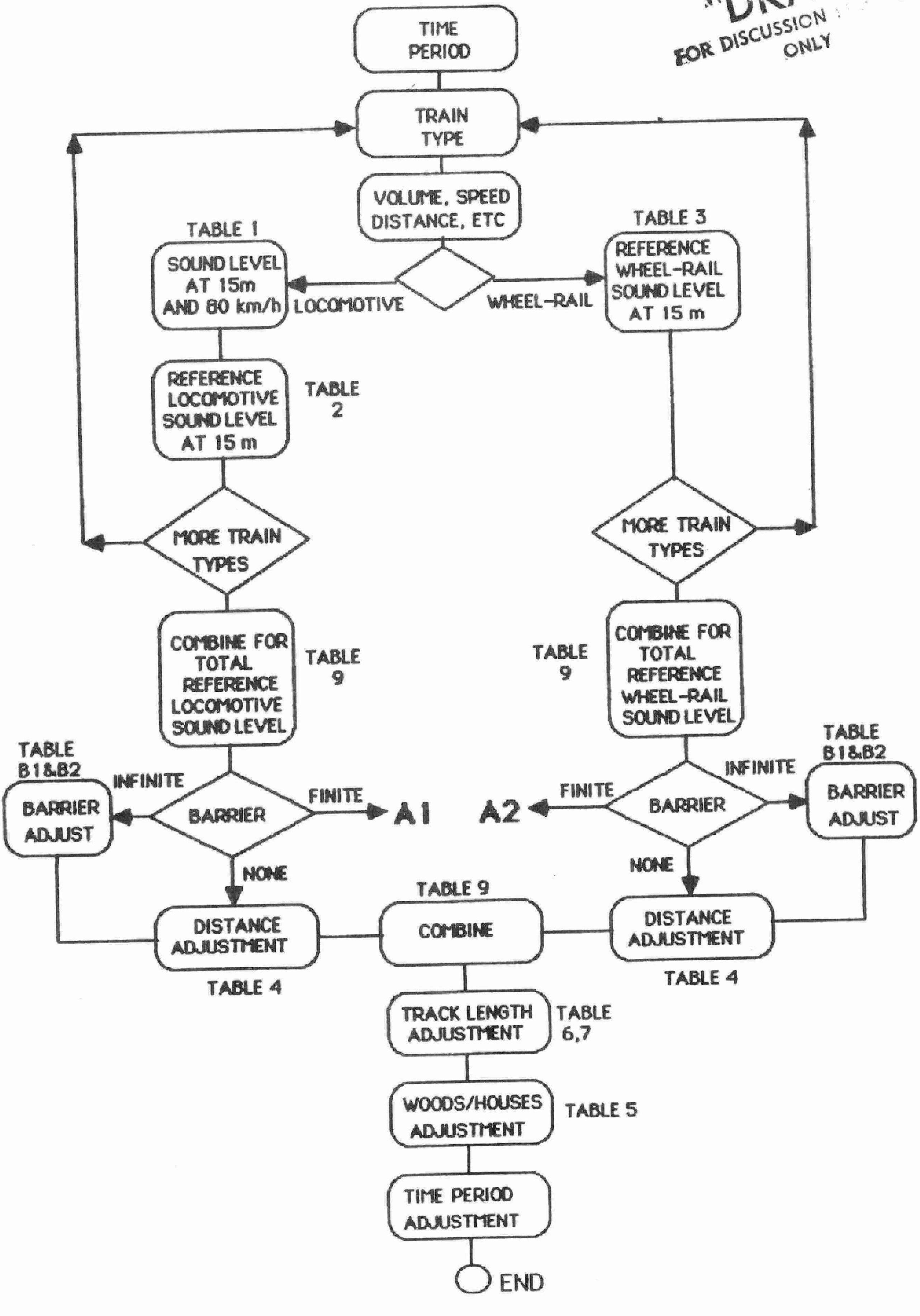
T. M. Barry and J. A. Reagan, "FHWA Highway Traffic Prediction Model", U.S. Federal Highway Administration, Report No. FHWA-RD-77-108, December 1978.

J. J. Hajek and F. W. Jung, "Simplified FHWA Noise Prediction Method", Report No. AE-82-05, Research and Development Branch, Ontario Ministry of Transportation and Communications, July 1982.

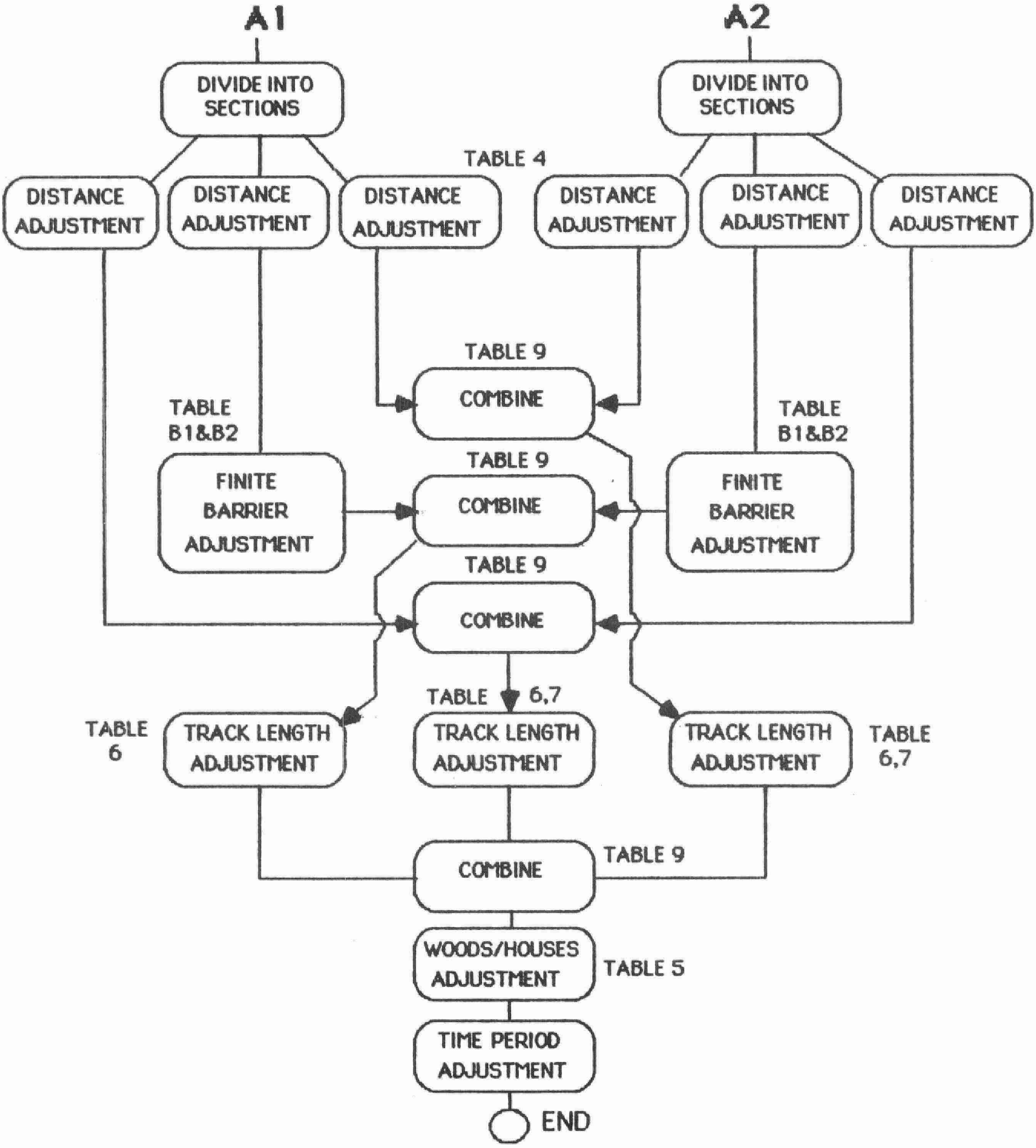
R. W. Krawczyniuk and J. J. Hajek, "Guidelines for Noise Barrier Cost Reduction Procedure, Stamina 2.0 and Optima", Report No. AE-83-01, Transportation Technology and Energy Division, Ontario Ministry of Transportation and Communications, May 1983.

Ontario Ministry of the Environment, "Guidelines for Road Traffic Noise Assessment", Environmental Approvals and Land Use Planning Branch, July 1986.

APPENDIX D: PROCEDURAL FLOWCHART



APPENDIX D: PROCEDURAL FLOWCHART (CONT.)



Appendix E

Train Noise Calculation Work Sheet

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TRAIN NOISE WORK SHEET

Name____________ Date____________ File____________ Description____________________

PART A - LOCOMOTIVE NOISE

1	Time Period									
2	Train Type									
3	No. of Trains									
4	No. of Locomotives/Train									
5	No. of Cars/Train									
6	Typical Train Speed (km/h)									
7	Total No. of Cars									
8	Total No. of Locomotives									
9	Average No. of Cars /Loco									
10	L eq @ 15m & 80 km/h (dBA)	Table 1								
11	Speed Adjustment (dBA)	Table 2								
12	Reference Leq (dBA)									
13	Overall Reference Leq (dBA)	Table 9								
14	Distance (m)									
	Effective Height									
15	Source (s) (m)									
16	Receiver (r) (m)									
17	Shielding (t+p) (m)									
18	Total Effective Height (m)									
19	Distance Adjustment (dBA)	Table 4								
	Barrier Shielding									
20	Ø 1 (degree)									
21	Ø 2 (degree)									
22	Finite Barrier Index	Table B1								
23	Path Length Difference (m)	Table B2								
24	Barrier Attenuation (dBA)	Table B2								
25	Locomotive Leq (dBA)									

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TRAIN NOISE WORK SHEET

Description________________________

PART B - WHEEL-RAIL NOISE

26	Train Type									
27	Typical Train Speed (km/h)									
28	Total No. of Cars									
29	Reference Leq @ 15m (dBA)	Table 3								
30	Overall Reference Leq (dBA)	Table 9								
31	Distance (m)									
	Effective Height									
32	Source (s) (m)									
33	Receiver (r) (m)									
34	Shielding (t+p) (m)									
35	Total Effective Height (m)									
36	Distance Adjustment (dBA)	Table 4								
	Barrier Shielding									
37	Ø 1 (degree)									
38	Ø 2 (degree)									
39	Finite Barrier Index	Table B1								
40	Path Length Difference (m)	Table B2								
41	Barrier Attenuation (dBA)	Table B2								
42	Wheel-Rail Leq (dBA)									

PART C

43	Loco &Wheel-Rail Leq (dBA)	Table 9		
	Adjustment			
44	Dense Woods (dBA)	Table 5		
45	Rows of Houses (dBA)	Table 5		
	Track Length			
46	Ø 1 (degree)			
47	Ø 2 (degree)			
48	Reflective (dBA)	Table 6		
49	Non-reflective (dBA)	Table 7		
50	Time Period (dBA)			
51	Loco &Wheel-Rail Leq (dBA)			
52	Overall Leq (dBA)			

APPENDIX C

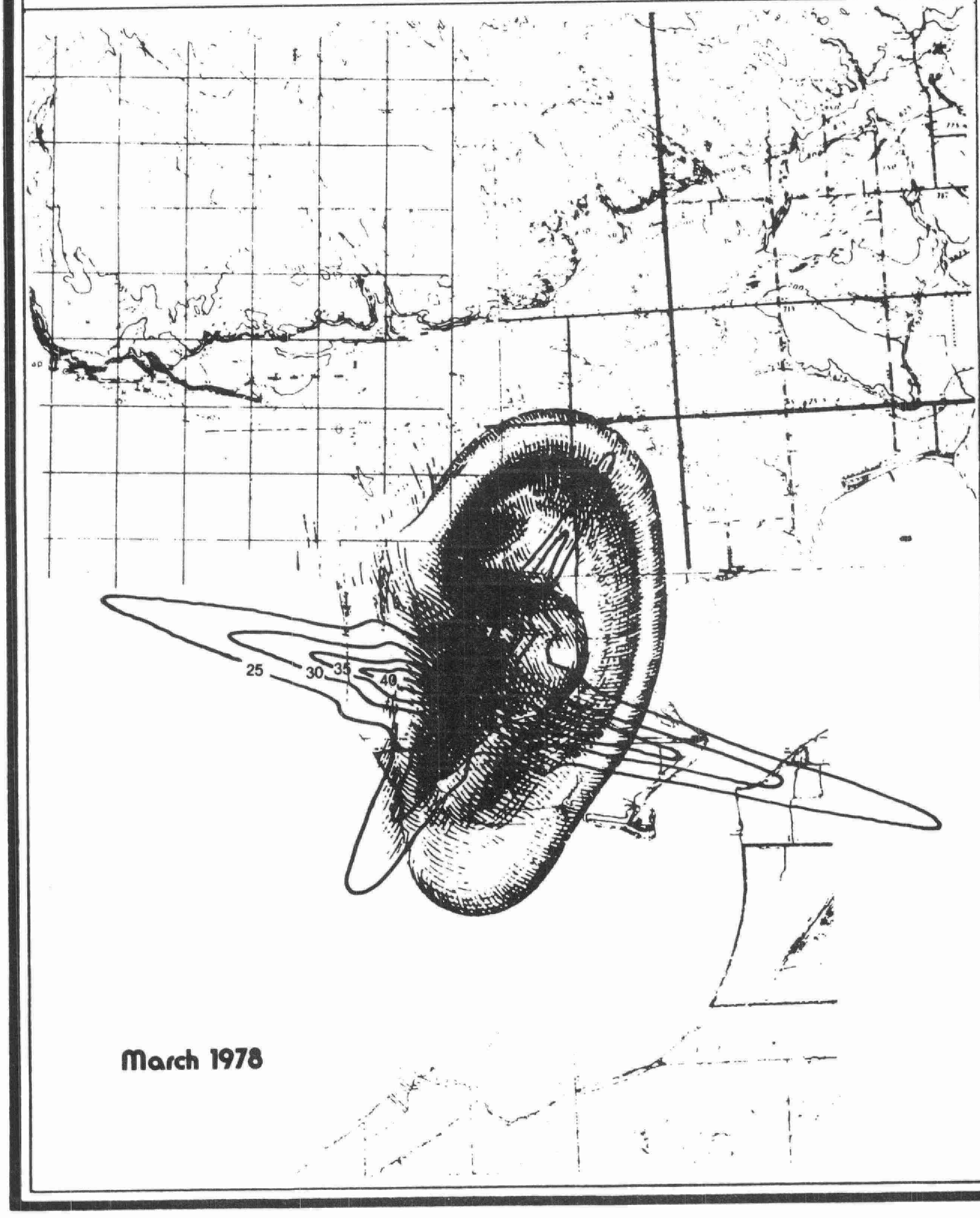
LAND USE POLICY NEAR AIRPORTS (NEF/NEP)

Ontario

Ministry of
Housing

Land-use policy near airports -

based on the Noise Exposure Forecast (NEF) system



March 1978

Provincial land use policies established in 1969 to protect lands near airports have been revised by the Ministry of Housing through the adoption of a more accurate system of measuring discomfort caused by aircraft noise.

The new policy is based on the NEF (Noise Exposure Forecast) system which reflects the noise produced by all types of aircraft at an airport, taking into consideration the number of flights, the duration of the noise, the time of day and the frequency components of the sound (pure tones).

All land use proposals near airports must now adhere to the NEF Land Use Compatibility Table (below). The applicable NEF values should be determined from NEF or NEP contour maps, based on contours supplied by Transport Canada or by the Department of National Defence (see opposite). This table has been designed to reflect CMHC policy related to residential development* and also contains policies for non-residential uses.

The general principle underlying the restrictions is that the outdoor noise level should govern permissible uses of a property. However, some indoor uses which make almost no use of the outdoors may be permitted to almost any noise level provided they meet CMHC standards for acoustic insulation and ventilation. The latter requirement is necessary to ensure that the acoustic insulation value is not lost through the opening of windows.

* New Housing and Airport Noise, N H A 5185 Metric Edition.

NEF land use compatibility table

Land uses (1)	Noise exposure forecast values				
	0	28	30	35	40
Group 1 **residential, passive use park, school, library, church, theatre, auditorium, hospital nursing home, camping or picnic area**	**In this range, noise is not usually a problem.**	**Discretionary Range** **All buildings must conform to Acoustic Design Criteria (2) (3).**	**Some annoyance will occur in this range but residential development will be acceptable if approved by the municipality (2)**	**No new Group 1 uses may be established in this range, except those for which the outdoor environment is irrelevant and which meet the Acoustic Design Criteria (3).**	
Group II hotel, motel, retail or service commercial, office, athletic field, playground, stadium, outdoor swimming pool	**In this range, noise is not usually a problem.**		**Discretionary Range** **The characteristics of each proposed use must be studied and appropriate noise insulation must be incorporated into building design (3).**		**Group II uses may not be established beyond the 40 NEF contour unless they are adequately insulated indoor uses (3).**
Group III industrial, warehousing, arena, general agriculture, animal breeding (4)	**In this range, noise is not usually a serious problem**			**Discretionary Range** **Most Group III uses are permissible in this range, provided ancillary uses are adequately insulated (3).**	

Notes

(1) Uses not specifically mentioned should be compared to the uses listed, classified in the most appropriate Group and regulated accordingly.

(2) For residential uses, refer to "New Housing and Airport Noise", N H A 5185-1-78 and any amendments thereto. Acoustic design must include adequate ventilation. The developer of a residential project must undertake to inform prospective tenants or purchasers of the possible noise problem.

(3) For non-residential uses, refer to the Acoustic Design Criteria opposite.

(4) Research has shown that most animals become conditioned to high noise levels. However, fur farms, and any use likely to create a bird hazard, such as a feed lot or stockyard, should not be located closer to an airport than as recommended by Transport Canada in "Land Use in the Vicinity of Airports", document S 77 4

Acoustic design criteria for non-residential uses

The procedure described in Section E of "New Housing and Airport Noise" should be adapted to meet required sound insulation for non-residential buildings. Table 1 below shows the correction factor to be used with Table 2 of the CMHC handbook to determine the Acoustic Insulation Factor (AIF) for other uses. AIF values corresponding to NEF values above the 35 contour are obtained by extrapollation from the figures on Table 2 below.

Table 1

Correction factor

Hotel, motel	no correction
Private office area, conference room etc.	-5
General office areas, retail stores	-10

Hospitals, theatres, auditoriums, churches, libraries, schools and nursing homes are subject to the same requirements as residential uses.

Example 1

The AIF for a retail store within the 30 contour, assuming the room has 3 components, would be 30 – 10 = 20.

With reference to Table A of the CMHC handbook, assuming a window area = 30% of the floor area, the window could be a single pane of 2 mm. glass. Within the 40 contour, the AIF would be 40 – 10 = 30 and a similar store would need a single pane of 4 mm. or 5 mm. glass.

Example 2

A private office associated with an industrial use in the vicinity of the 45 NEF contour would have an AIF of 46 – 5 = 41. (Assuming 4 components). Assuming a window area = 25% of the floor area, triple glazing (a WT2-W1 window) would be required.

Table 2

Acoustic insulation factor †

No. of components forming room envelope	NEF												
	25	26	27	28	29	30	31	32	33	34	35	40	45
1	20	21	22	23	24	25	26	27	28	29	30	35	40
2	23	24	25	26	27	28	29	30	31	32	33	38	43
3	25	26	27	28	29	30	31	32	33	34	35	40	45
4	26	27	28	29	30	31	32	33	34	35	36	41	46

† Table 2 of the CMHC handbook "New Housing and Airport Noise" (1978 edition), expanded to include NEF values above 35.

NEF and NEP contour maps *

1. NEF contour maps

The currently available NEF contour maps which should be used are listed to the right. With the exception of Toronto International Airport (Malton), they are obtainable from local offices of the Canada Mortgage and Housing Corporation (C.M.H.C.). The Toronto Malton map is available from the Local Planning Policy Branch, Ministry of Housing, 3rd Floor, 56 Wellesley Street West, Toronto, M7A 1K4. (416-965-3938).

Airport	Date of Latest Revision	Projection Date
Ottawa	June, 1972	Summer 1976
Hamilton	April, 1973	* *
London	Jan., 1975	Summer 1978
Thunder Bay	Oct., 1974	1976 +
Carp	May, 1973	* *
Kingston	Sept., 1978	1986
Sudbury	June, 1973	1976
Buttonville	Aug., 1973	* *
Toronto Island	April, 1978	1990
Oshawa	Aug., 1978	1985
Maple	Sept., 1973	* *
Waterloo-Wellington	April, 1977	1985
Sault Ste. Marie	Sept., 1974	1976
C.F.B. Trenton	Jan., 1979	1984
Brantford	Aug., 1977	1991
North Bay	Aug., 1978	1985
Sarnia	Aug., 1978	1986
Pembroke	Oct., 1978	1986
Wiarton	Feb., 1979	* *
Toronto (Malton)* * *	Aug., 1979	1986

---

* This list was updated in January, 1980.

* * General Aviation (No date).

* * * Land use proposals should not conflict with the 1995 NEP or with the 1986 NEF contours for Toronto (Malton).

2. NEP contour maps

In some cases, the relatively short-range NEF maps published by C.M.H.C. are not considered appropriate by the Ministry of Housing for land use planning purposes and the Noise Exposure Projection (NEP) contours representing a longer range projection should be used. The NEP contour maps which are currently available from the Local Planning Policy Branch, Ministry of Housing, are listed below.

Airport	Date of Latest Revision	Projection Date
Windsor	Oct., 1978	1985
Toronto (Malton)*	July, 1976	1995

* Land use proposals should not conflict with the 1995 NEP or with the 1986 NEF contours for Toronto (Malton).

Up-to-date contours for other airports are scheduled to be produced by Transport Canada and will be added to the list. In addition, it is expected that existing contour maps will be reviewed and updated from time to time.

Published by:
Communications Branch
Ministry of Housing

2M/4-80/PW-43

APPENDIX D

ADJUSTMENT PROCEDURES FOR OUTDOOR SOUND REFLECTION

ADJUSTMENT PROCEDURES FOR OUTDOOR SOUND REFLECTION

ONTARIO MINISTRY OF THE ENVIRONMENT
ENVIRONMENTAL APPROVALS AND LAND USE PLANNING BRANCH
DECEMBER 1986

ADJUSTMENT PROCEDURES FOR OUTDOOR SOUND REFLECTION

1.0 Introduction

Recently the Noise Assessment Unit released a road traffic prediction model titled "Guidelines for Road Traffic Noise Assessment". The prediction scheme is to be used to evaluate the traffic noise level for the purpose of land use assessment, approvals of new installations and abatement. Adjustment for distance, ground absorption, dense woods and barriers were also presented in the document. The effect of sound reflections from facades which depend on site-specific conditions were left to be included in appropriate sections in the acoustic manuals currently under preparation by the Ministry staff.

To aid consultants who are working on noise assessment of land use evaluations prior to the issue of the acoustic manuals, an early edition of the procedure for consideration of sound reflection is issued in the following brief paper.

2.0 Background

Most of the procedures that are currently in use by the Ministry assume the prediction or the measurement of sound in sites, where there are no hard reflecting surfaces. The major application or objective of the Ministry's procedure is to estimate the outdoor sound level, either by prediction or by measurement. However, in the majority of the cases, where sound is predicted near an exterior

surface (building facades for instance) the sound level will vary considerably due to wavelike character of sounds. A proper definition of the "Outdoor sound level near exterior facades" is required. An appropriate procedure must also be recommended.

A number of researchers have studied the effect of reflection from exterior surfaces on the outdoor noise levels. References 1, 2, and 3 report results of measurements conducted to investigate proper measurement procedure that would take into account the influence of exterior surfaces. Reference 4 is an A.S.T.M. Standard released in 1984 which synthesizes all the available methods into a single standard. Reference 5 summarizes the insulation capabilities of exterior surfaces when the incident sound is not perpendicular to the surface. Reference 6 discusses procedures that can be applied when predicting outdoor noise levels.

Only a sample list of available literature has been presented. Even though the bibliography is not exhaustive, the quoted references address the main concerns in sufficient depth and are adequate to formulate the procedures that are required.

3.0 Discussion

There are three main areas of concern for the Ministry where the evaluation of the outdoor noise level is of primary interest, namely:

a) Land Use assessment
b) Approvals of new installations
c) Abatement

The determination of outside noise levels for abatement and approvals is usually obtained through a measurement program. The measurements are conducted on-site where the exterior surface already exists. The measurement procedures outlined in many of the Ministry publications, if properly executed, would include the effect of reflection and no additional adjustments are necessary.

In Land Use assessment, most of the currently available procedures use well established theoretical prediction schemes to evaluate the outdoor sound level. The calculations predict a "free-field" sound level at receptor locations where the proposed structures are to be constructed. However, the prediction methods have made no allowance for reflections from the building facade.

The guideline procedures presented here apply to noise prediction techniques designed for the calculation of free-field (outdoor) sound levels and consists of adjustment factors to be applied to the predicted sound level.

4.0 Guideline Procedures

The National Research Council of Canada publication B.P.N. 56 (Reference 6) "Controlling Sound Transmission into Buildings" summarizes the measurement results into applicable guidelines. The above reference has been used as a basis for the adjustments present here. For detailed description of the method and the rationale for the procedures, refer to Quirt (6).

The three areas of concern where the adjustment to "free-field level" applies are as follows:

a) Outdoor living areas:

The sound level at outdoor living areas is usually estimated during daytime hours. The receiver location is 3 metres from a building facade and 1.5 metres above ground level.

b) Near building facades:

The sound level outside the bedroom window during night time hours is evaluated. For a single family dwelling the receiver location is usually about 4.5 metres above the ground level, and just outside the window.

c) Amount of sound insulation required:

When the outside level exceeds a certain limit, exterior building components must be properly specified, taking into account the required amount of insulation needed.

The applicable methods to be used in each of the above situations are given below.

4.1 Level in Outdoor Living Areas

The usual practice in land use planning is to estimate the outdoor living area noise level (L_{eq}, dBA) during the daytime hours at 3 metres away from the building facade. The prediction methods calculate "the free-field" sound level. To account for the reflections from the building facade, 2 dB adjustments should be added to the predicted "free-field" outdoor sound level.

Note:

1. The above adjustment is also valid for corner lots even when there is an acoustic fence parallel to the noise source, and the fence has a wrap-around the property line. (See Figure 1). Municipally approved fences are not very high, and the reflections from the fence are minimal.

2. If the outdoor living area is located on the shielded side (away from the noise source) of the building facade, no extra adjustment is required.

4.2 Level Near Building Facades

In addition to compliance with the noise criteria at outdoor living areas, the Ministry procedures require the evaluation of outside levels near the bedroom window. The outside level would determine the proper house ventilation as well as the appropriate specifications for building components. To account for the reflections from the facade, 3 dB adjustments should be added to the predicted outside "free-field" sound level near the building facades.

4.3 Sound Insulation Requirements

The choice of exterior building components satisfying the Building Code requirement is adequate in most instances. However, if the outside noise level close to the facade, particularly at second storey elevations, exceeds the criteria, the building components have to be designed to provide adequate sound insulation. The required amount of sound insulation is determined by the AIF (Acoustic Installation Factor) number. AIF is a composite number developed by the National Research Council of Canada,

which is determined among others by the STC (Sound Transmission Class) of the building component. The STC of the wall, window, roof or door is usually determined by laboratory methods where the incident sound field is diffused. Such a sound field is commonly denoted as Random Incident Field. In some instances the sound field is incident only along a narrow range of angles and the transmission loss value decreases. An example is that of an exterior wall of a single family dwelling which is perpendicular to a roadway or a railway track (e.g. exterior surface 2 in Figure 1). The required AIF values in this case must be adjusted accordingly. The proper adjustment values are given in Table 1.

5.0 Conclusions

A set of guideline procedures was presented to account for the reflection from building facades. The reduction of the transmission loss properties due to the acute angles of sound incidence was also discussed, and proper adjustment factors were presented as part of the procedures.

LIST OF REFERENCES

1.0 Quirt, J.D. "Sound Levels Around Buildings near Roadways". Canadian Acoustics, Volume 10, No.1, 1982, pp 13-18.

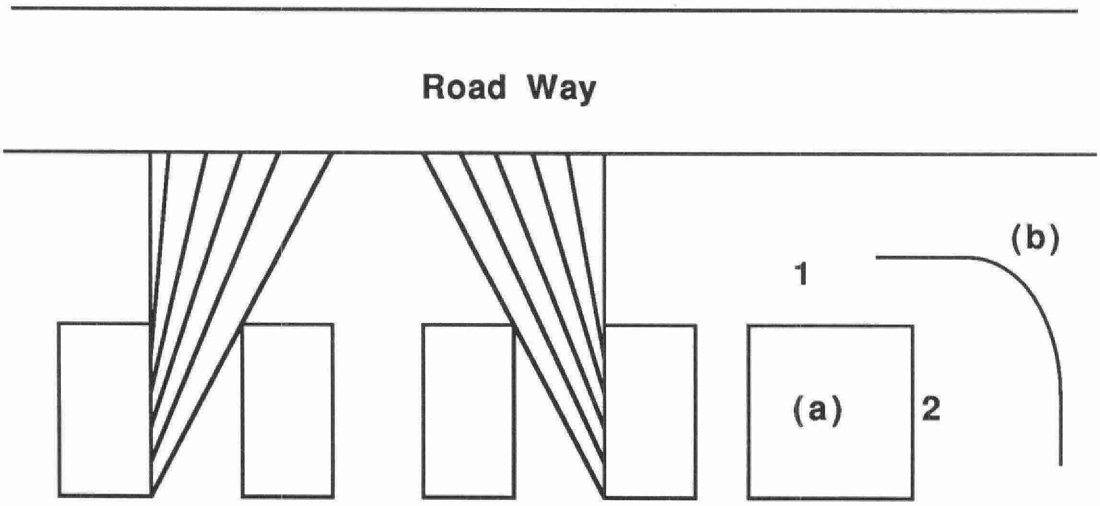
2.0 Quirt, J.D. "Sound Fields near Exterior Building Surfaces". Journal of the Acoustical Society of America. Volume 77, No.2, 1985, pp 566-557.

3.0 Hall, F.L. and Bechrakis, N. "The Effect of the Angle of Incidence on Residential Acoustical Insulation" Noise Control Engineering Journal, Volume 22, No. 2, 1984, pp 42-47.

4.0 Standard Guide for "Field Measurement of Airborne Sound Insulation of Building Facades and Facade Elements". A.S.T.M. Standard E966-84.

5.0 Sabine H.J., Lacher, M.B., Flynn, D.R., and Cluindry, T.L., "Acoustical and Thermal Performance of Exterior Residential Walls, Doors and Windows". National Bureau of Standards, Washington D.C., 1975.

6.0 Quirt, J.D. "Controlling of Sound Transmission into Building". National Research Council of Canada. B.P.N. 56, 1985.



(a) Corner Lot

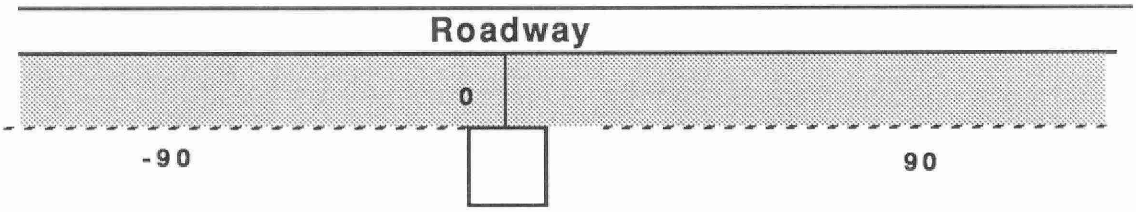
1,2 : Exterior Surfaces

(b) Wrap around Acoustic Fence

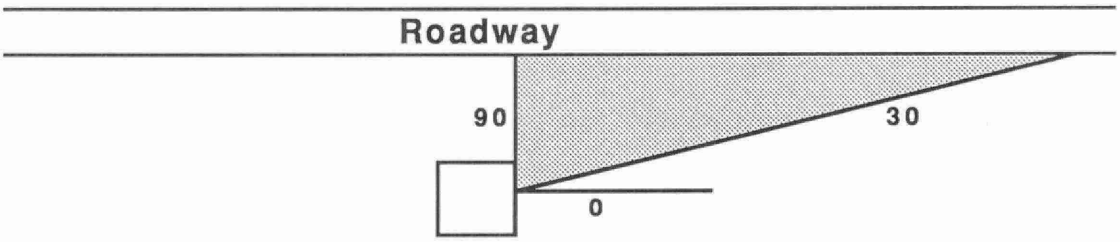
Figure 1. Sketch of a corner lot exposed to the road

Angles at which sound arrives (0=perpendicular to surface)	Correction
60 to 90 degrees	3
40 to 90 degrees	2
30 to 90 degrees	1
0 to 90 degrees	0

Note: The angles are defined by the angle between the perpendicular to the affected surface and the angle (or range of angles) of the sound incidence as shown below.



Angle: 0 to 90 degrees



Angle: 30 to 90 degrees

Table 1. Correction for source geometry to be added to the required AIF. (Source: Reference 6.)

(The angular range best describing the dominant noise source should be used)

APPENDIX E

MANUAL FOR COMPUTER PROGRAM FOR ROAD TRAFFIC NOISE ASSESSMENT

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MANUAL FOR COMPUTER PROGRAM
FOR
ROAD TRAFFIC NOISE ASSESSMENT

PC-STAMSON 1.1

COMPUTER PROGRAM FOR ROAD TRAFFIC NOISE ASSESSMENT

ONTARIO MINISTRY OF THE ENVIRONMENT
ENVIRONMENTAL APPROVALS AND LAND USE PLANNING BRANCH
NOVEMBER 1986

PC-STAMSON 1.1
MOE PROGRAM FOR ROAD TRAFFIC NOISE ASSESSMENT

INTRODUCTION

PC-Stamson is a computer program for the IBM PC or a compatible personal computer that calculates the noise level at a point of reception produced by road traffic. The program uses the mathematical expressions that yielded the prediction tables contained in the MOE Guidelines for Road Traffic Noise Assessment, July 1986. Results obtained using this program are generally more accurate and, therefore, preferable.

The calculation is based on a model established by the U.S. Federal Highway Administration; however, it includes extensions as well as simplifications specific to practices and requirements of the Ministry of Transportation and Communications and the Ministry of the Environment.

The objective of the program is to provide a simple but comprehensive prediction of road traffic noise level, including adjustments for distance , ground and shielding (barrier, housing, woods) attenuation.

The program had been written using two computer languages: dBase III and Basic. The former was utilized for its ability to perform full screen input and editing and the latter was chosen because it can handle mathematical computation and is commonly available. Subsequently, the source code was compiled using Clipper compiler (dBase III) and Basic compiler.

In order to achieve simplicity and clarity, the program is driven by menus and, where possible, utilizes schematic or pictorial presentations. Further, help menus are provided at most stages.

PROGRAM STRUCTURE

The program has been structured into several modules: the first module allows the user to input all relavant parameters and thus create an Input File which is then passed on to the calculation module. The Input File can subsequently be edited using two different routines. House keeping functions such as directory listing and file deletion are also provided in a separate section.

Due to its structured format, the program uses several files during execution and the following files must exist in the directory:

STAMSON.EXE RESULT.DBF
BSTAMSON.EXE RESULT2.DBF
STAM_SON.DBF TEMP.DBF
USTAM_SO.DBF TEMP2.DBF

STAMSON.EXE and BSTAMSON.EXE are the compiled dBaseIII and Basic programs. The DBF files are data base files required during execution; STAM_SON.DBF file, for example, contains the default input parameters used for execution of BSTAMSON.EXE.

RUNNING THE PROGRAM

The program is executed by the following command:

```
STAMSON <Return>
```

The first screen identifies the project and the date; pressing <Return> takes the execution to the Main Menu screen that identifies the five program modules. Pressing F1 key opens the Help screen for the Main Menu; additional "help" instructions have been included with most screens. Attached are copies of all the screens, icluding Help screens, that the program displays during an execution. The example uses the default values.

OPTION 1: CREATE NEW DATA SET

In this module, the user enters all the input parameters using specially designed panels. The input fields in each panel are accessed using the Up/Down keys on the numeric pad or the <Return> key. Pressing <Return> in the last field on the screen will open the next panel.

If unchanged, the program uses default name STAM_SON for for the Input File name in the first, File Allocation panel. File STAM_SON is used to pass input parameters from the Input/Edit modules to the calculation module. If the user wishes to store the input parameters in a different file after the execution is completed, the second file name, also using a default name STAM_SON, must be entered. In this way, a number of Input Files may be established for subsequent execution.

The last panel in this module is a Verification panel where all the input parameters are displayed for verification; answering N(o) takes the execution to the Roadway Parameters panel while Y(es) takes the execution to the Main Menu.

OPTION 2: EDIT EXISTING FILE USING PANEL

This module is very similar to option 1 with the exception that the user cannot change the measurement units. The user edits the input information entered in option 1.

OTION 3: EDIT EXISTING FILE

Special care must be taken when using Option 3 which allows the user to edit the input file directly without program control. Where Options 1 and 2 impose constraints on the input parameters, Option 3 offers no such limitations and must be used with caution.

OPTION 4: RUN STAMSON

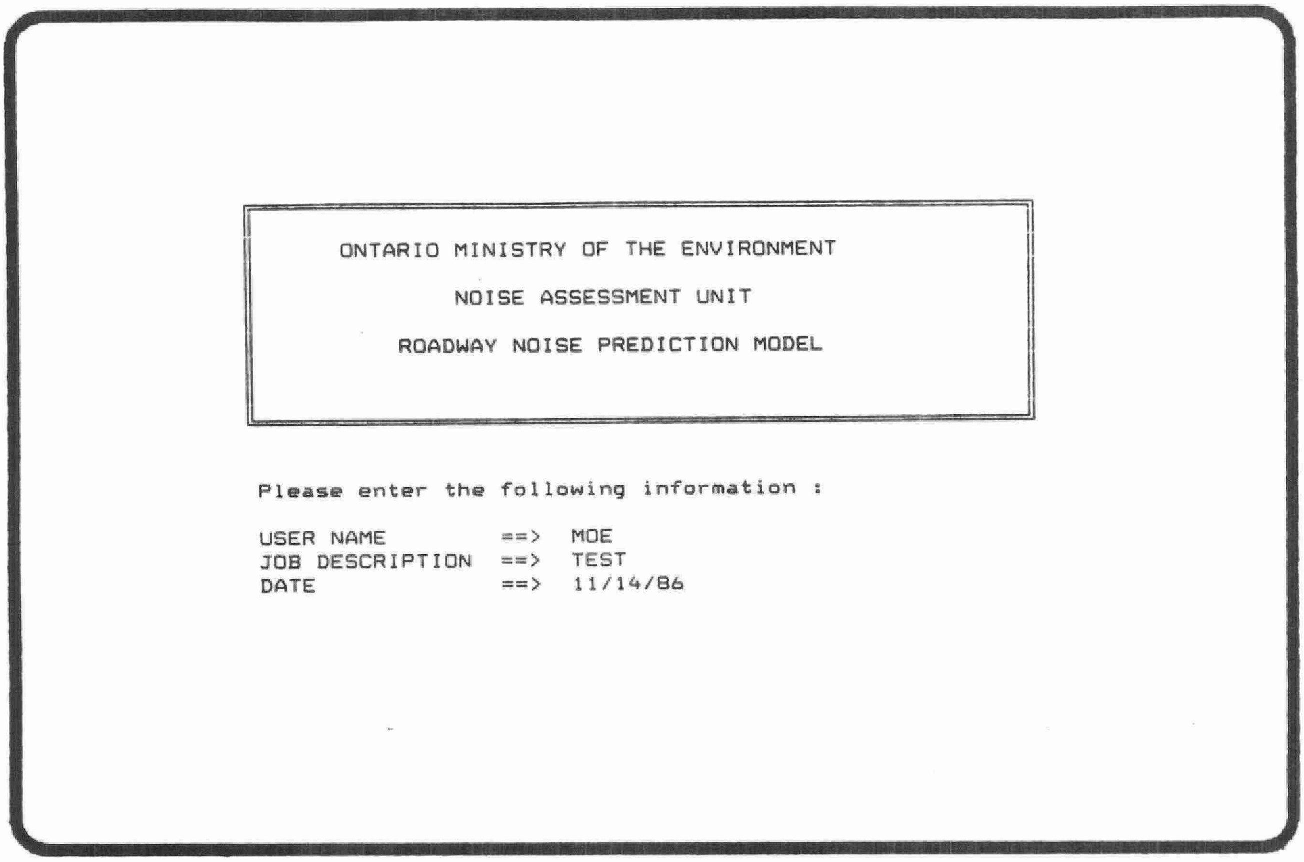
In this option, the calculation module is accessed and the calculation using the previously input parameters is performed. Results are shown on the screen with option of hard copy printout.

OPTION 5: HOUSE KEEPING

File directory listing and file deletion of unwanted data base file is performed in this module.

MAIN PROGRAM

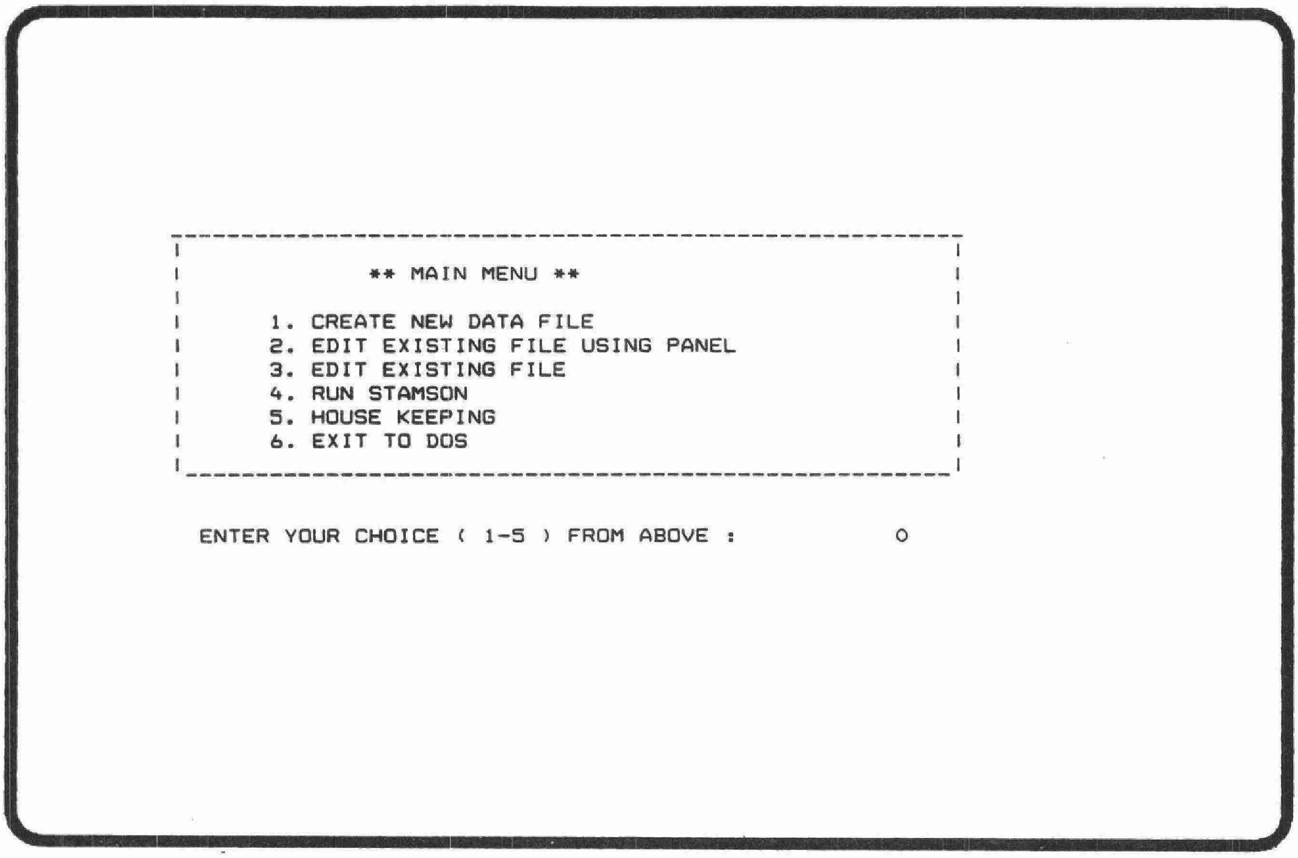
PROGRAM SCREEN



```
ONTARIO MINISTRY OF THE ENVIRONMENT

      NOISE ASSESSMENT UNIT

  ROADWAY NOISE PREDICTION MODEL


Please enter the following information :

USER NAME         ==>   MOE
JOB DESCRIPTION   ==>   TEST
DATE              ==>   11/14/86
```

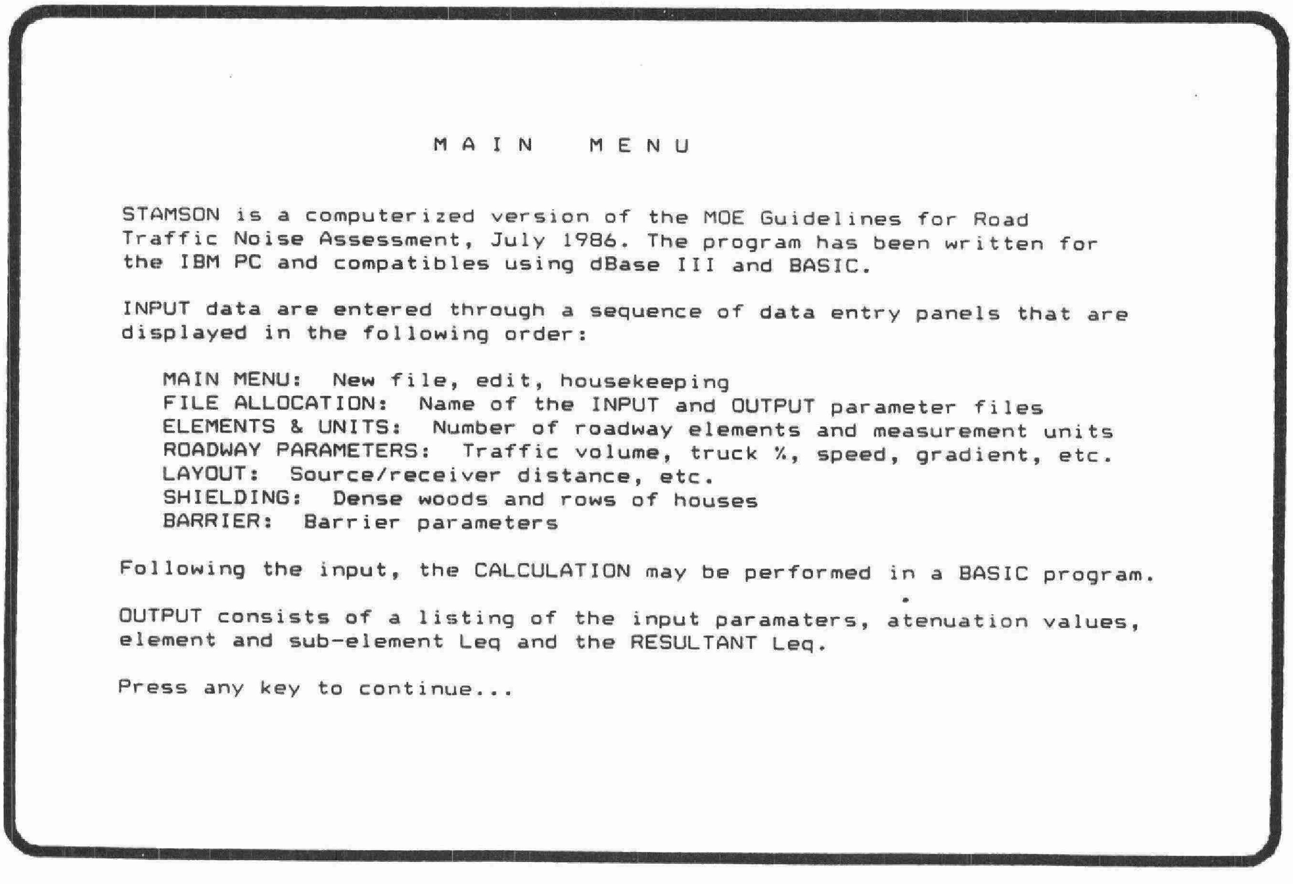
HELP SCREEN

PROGRAM SCREEN



```
 ------------------------------------------------------------
|                                                            |
|               ** MAIN MENU **                              |
|                                                            |
|        1. CREATE NEW DATA FILE                             |
|        2. EDIT EXISTING FILE USING PANEL                   |
|        3. EDIT EXISTING FILE                               |
|        4. RUN STAMSON                                      |
|        5. HOUSE KEEPING                                    |
|        6. EXIT TO DOS                                      |
|------------------------------------------------------------|

  ENTER YOUR CHOICE ( 1-5 ) FROM ABOVE :           0
```

HELP SCREEN

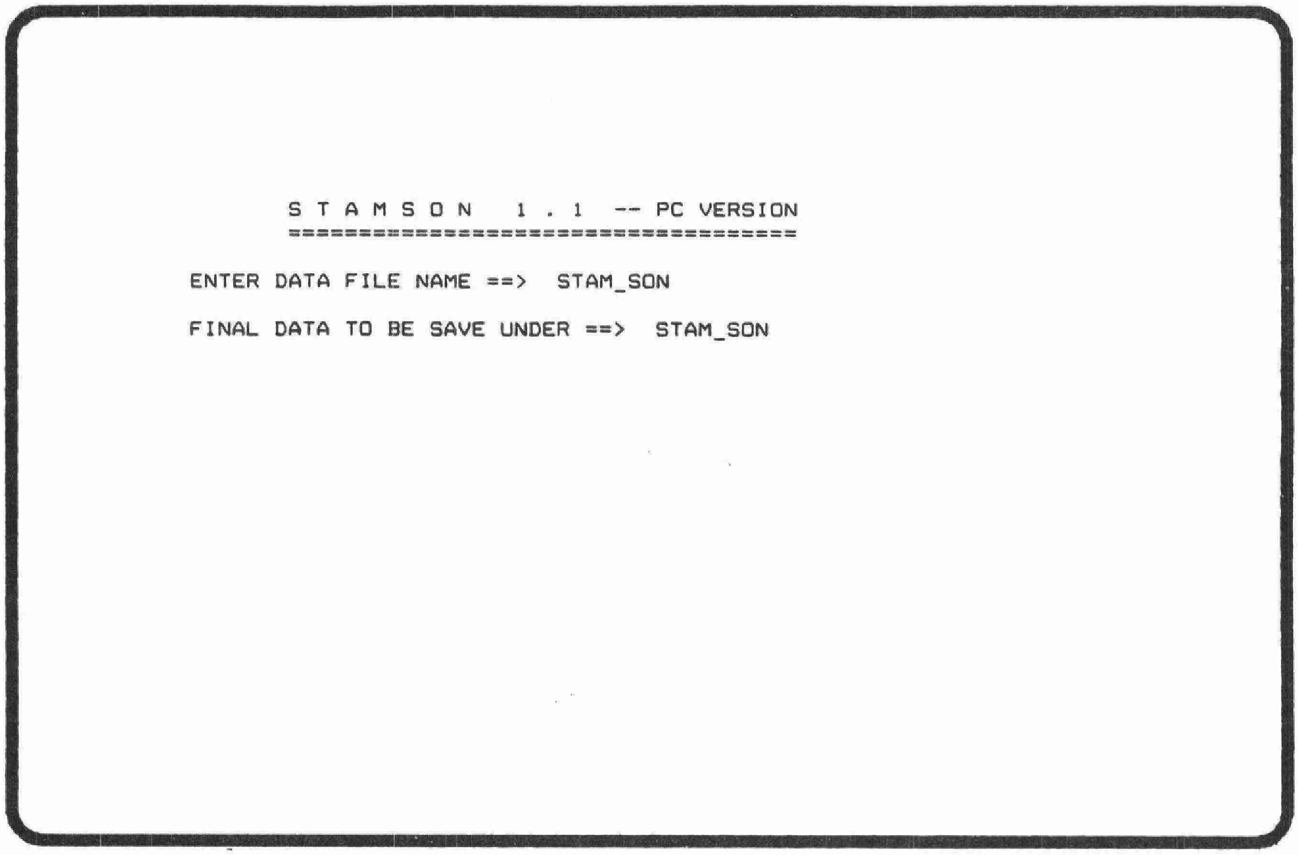


```
                        M A I N   M E N U

STAMSON is a computerized version of the MOE Guidelines for Road
Traffic Noise Assessment, July 1986. The program has been written for
the IBM PC and compatibles using dBase III and BASIC.

INPUT data are entered through a sequence of data entry panels that are
displayed in the following order:

   MAIN MENU:  New file, edit, housekeeping
   FILE ALLOCATION:  Name of the INPUT and OUTPUT parameter files
   ELEMENTS & UNITS:  Number of roadway elements and measurement units
   ROADWAY PARAMETERS:  Traffic volume, truck %, speed, gradient, etc.
   LAYOUT:  Source/receiver distance, etc.
   SHIELDING:  Dense woods and rows of houses
   BARRIER:  Barrier parameters

Following the input, the CALCULATION may be performed in a BASIC program.

OUTPUT consists of a listing of the input paramaters, atenuation values,
element and sub-element Leq and the RESULTANT Leq.

Press any key to continue...
```

MENU OPTION 1:

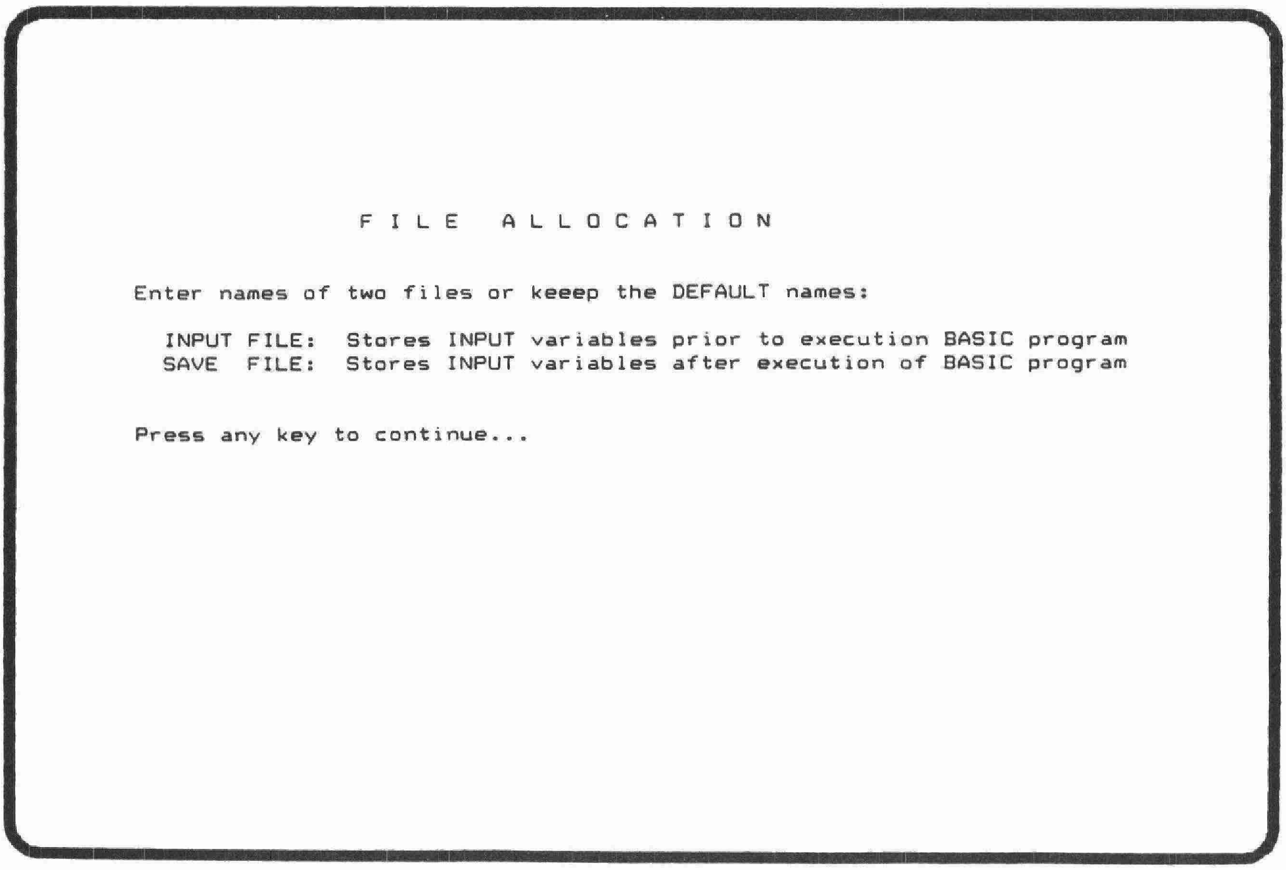
CREATE NEW DATA SET

PROGRAM SCREEN



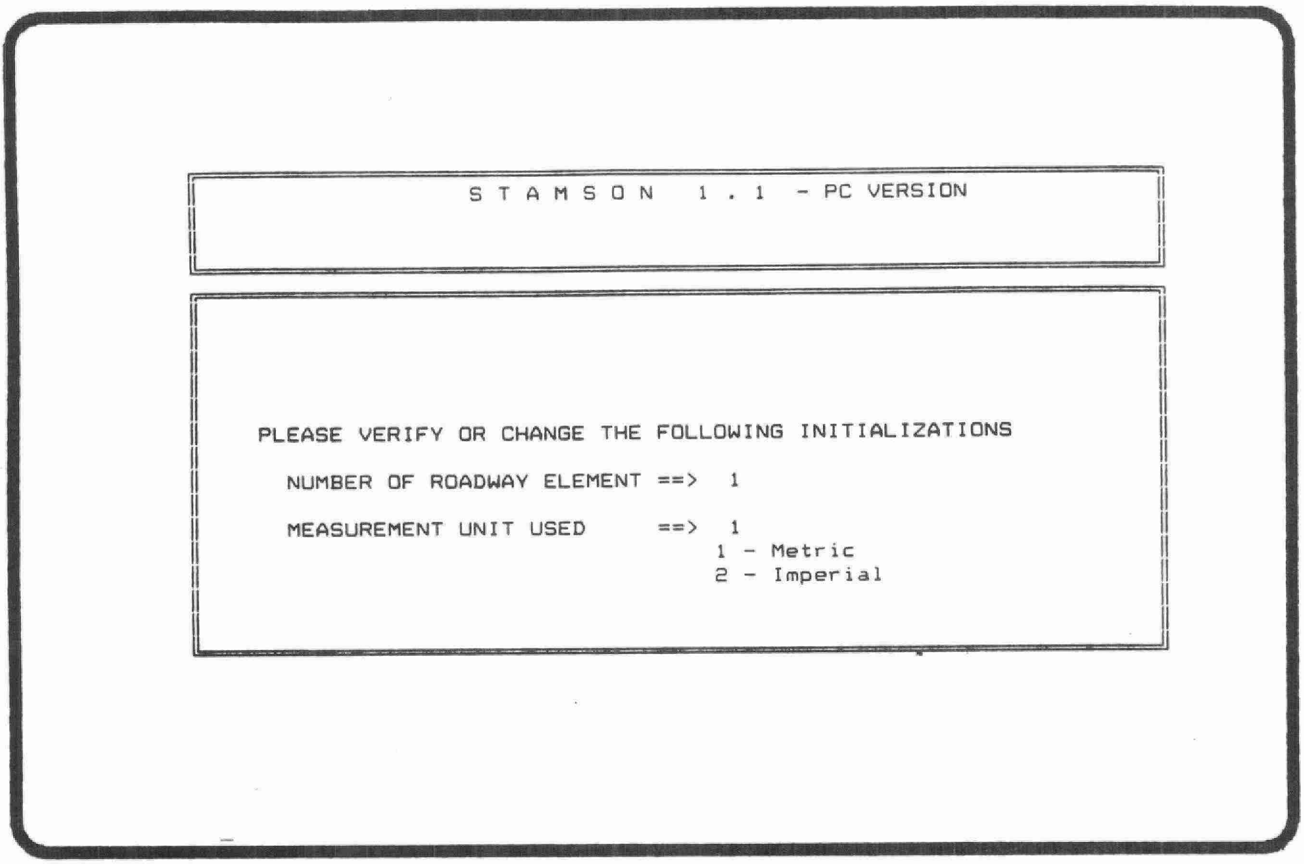
```
              S T A M S O N   1 . 1  -- PC VERSION
              ====================================

       ENTER DATA FILE NAME ==>  STAM_SON

       FINAL DATA TO BE SAVE UNDER ==>  STAM_SON
```

HELP SCREEN



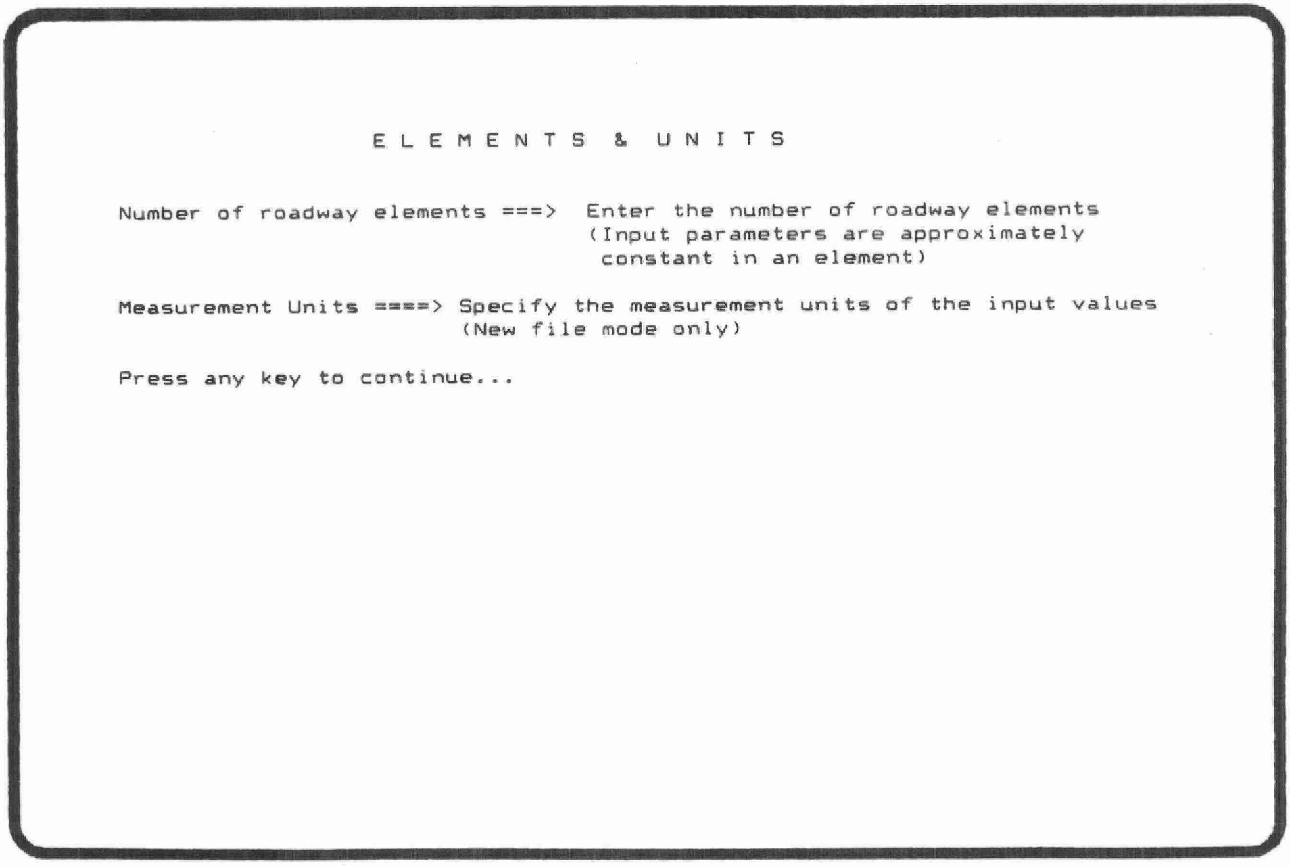
```
                    F I L E   A L L O C A T I O N

       Enter names of two files or keeep the DEFAULT names:

         INPUT FILE:  Stores INPUT variables prior to execution BASIC program
         SAVE  FILE:  Stores INPUT variables after execution of BASIC program


       Press any key to continue...
```

PROGRAM SCREEN



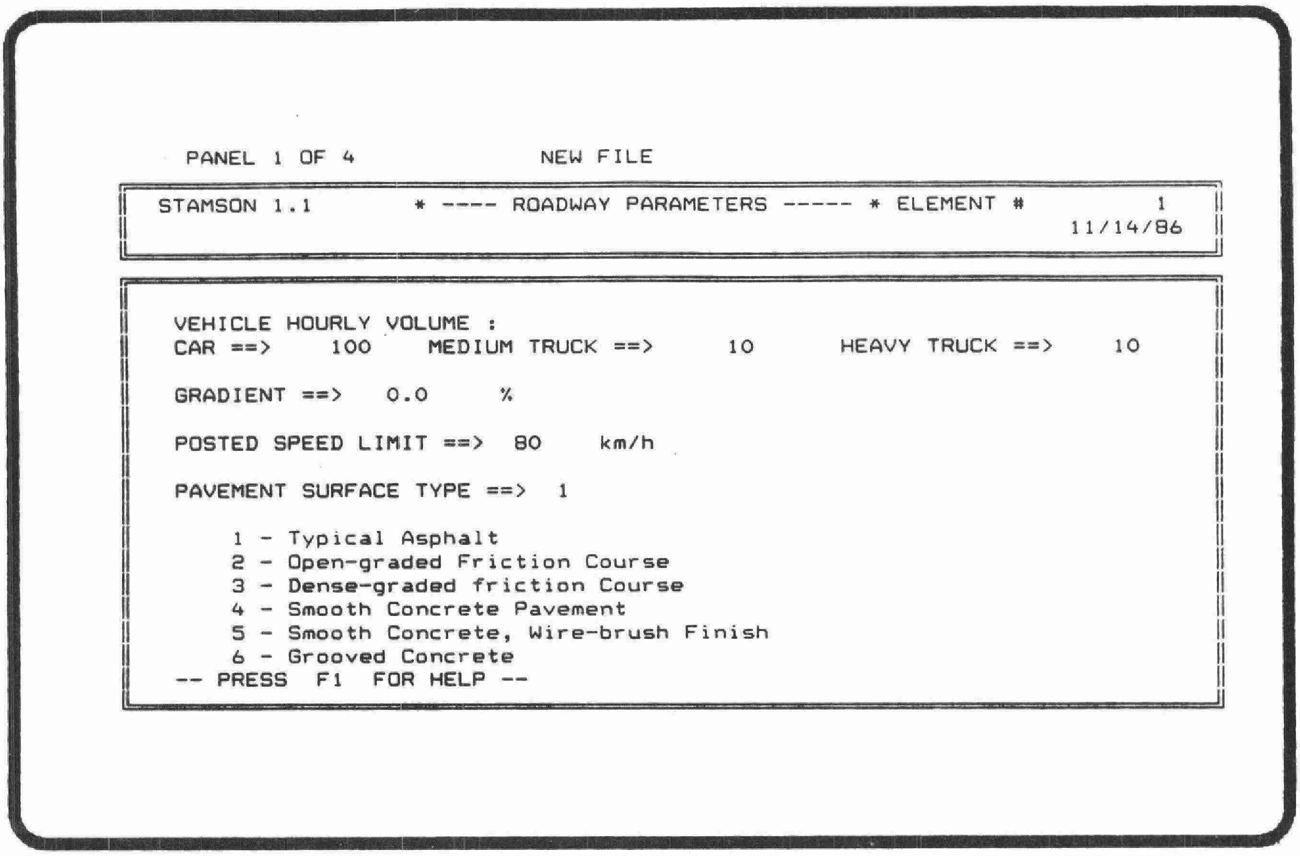
```
                    S T A M S O N   1 . 1  - PC VERSION


  PLEASE VERIFY OR CHANGE THE FOLLOWING INITIALIZATIONS

    NUMBER OF ROADWAY ELEMENT ==>  1

    MEASUREMENT UNIT USED     ==>  1
                                 1 - Metric
                                 2 - Imperial
```

HELP SCREEN



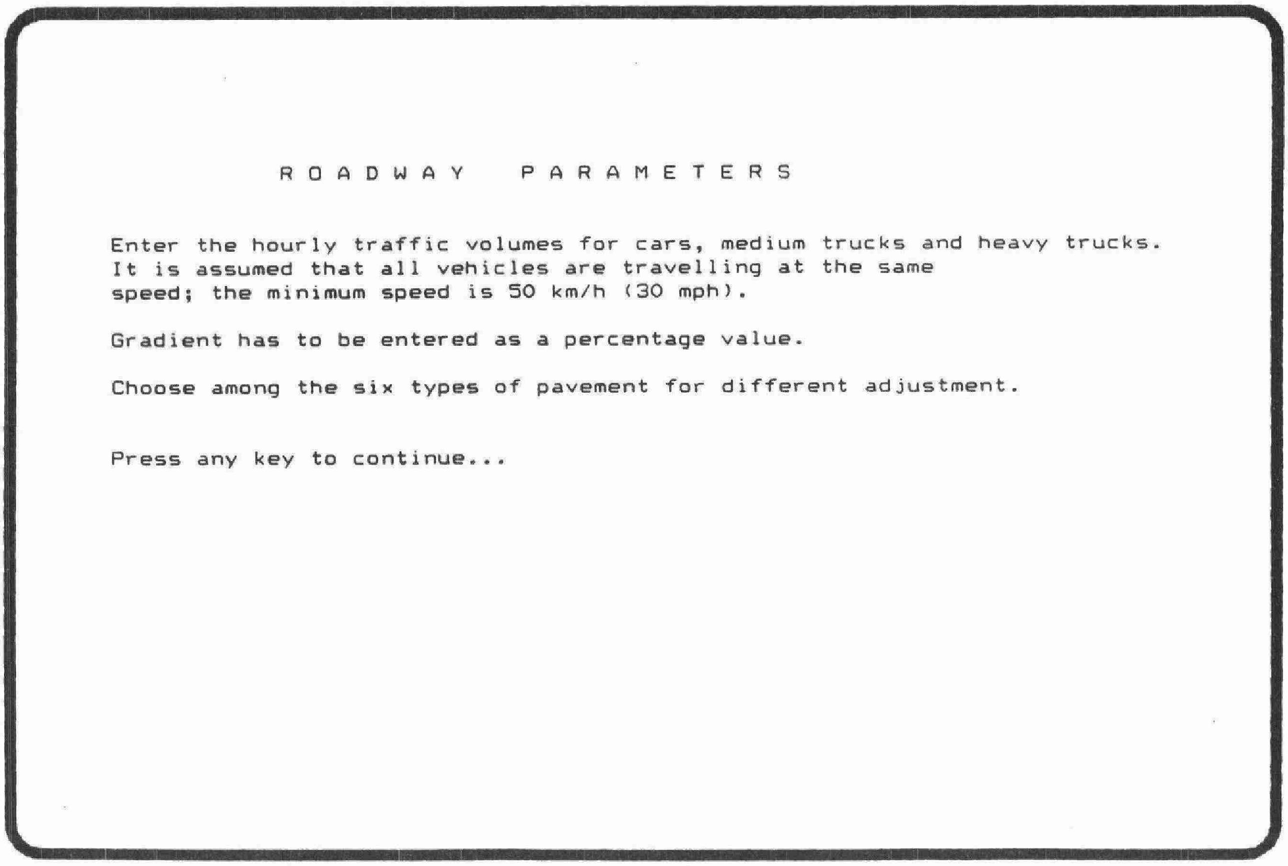
```
                 E L E M E N T S  &  U N I T S

Number of roadway elements ===>  Enter the number of roadway elements
                                 (Input parameters are approximately
                                  constant in an element)

Measurement Units ====> Specify the measurement units of the input values
                        (New file mode only)

Press any key to continue...
```

PROGRAM SCREEN



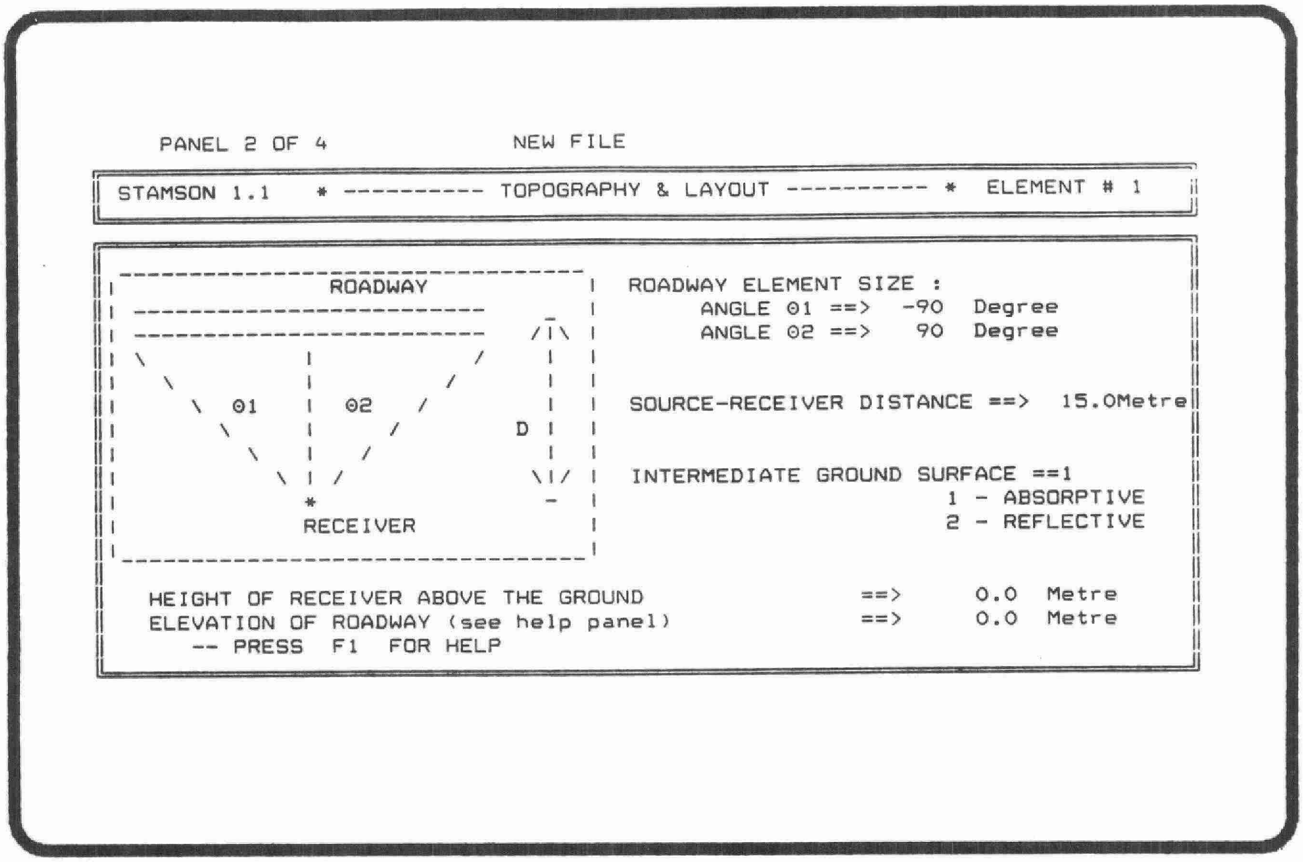
```
PANEL 1 OF 4                 NEW FILE

STAMSON 1.1        * ---- ROADWAY PARAMETERS ----- * ELEMENT #         1
                                                                 11/14/86

VEHICLE HOURLY VOLUME :
CAR ==>     100    MEDIUM TRUCK ==>     10      HEAVY TRUCK ==>     10

GRADIENT ==>   0.0     %

POSTED SPEED LIMIT ==>  80    km/h

PAVEMENT SURFACE TYPE ==>  1

    1 - Typical Asphalt
    2 - Open-graded Friction Course
    3 - Dense-graded friction Course
    4 - Smooth Concrete Pavement
    5 - Smooth Concrete, Wire-brush Finish
    6 - Grooved Concrete
-- PRESS  F1  FOR HELP --
```

HELP SCREEN



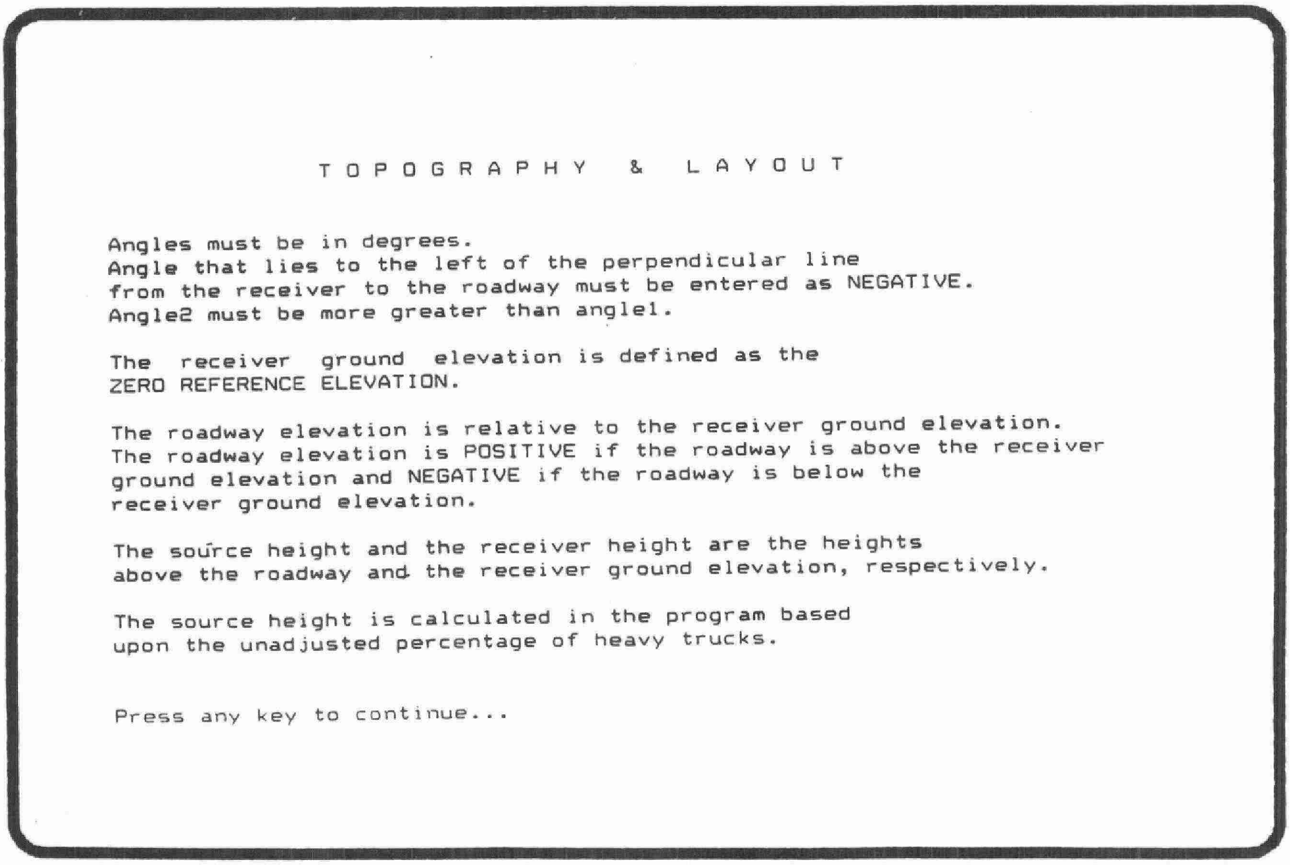
```
          R O A D W A Y   P A R A M E T E R S


Enter the hourly traffic volumes for cars, medium trucks and heavy trucks.
It is assumed that all vehicles are travelling at the same
speed; the minimum speed is 50 km/h (30 mph).

Gradient has to be entered as a percentage value.

Choose among the six types of pavement for different adjustment.


Press any key to continue...
```

PROGRAM SCREEN



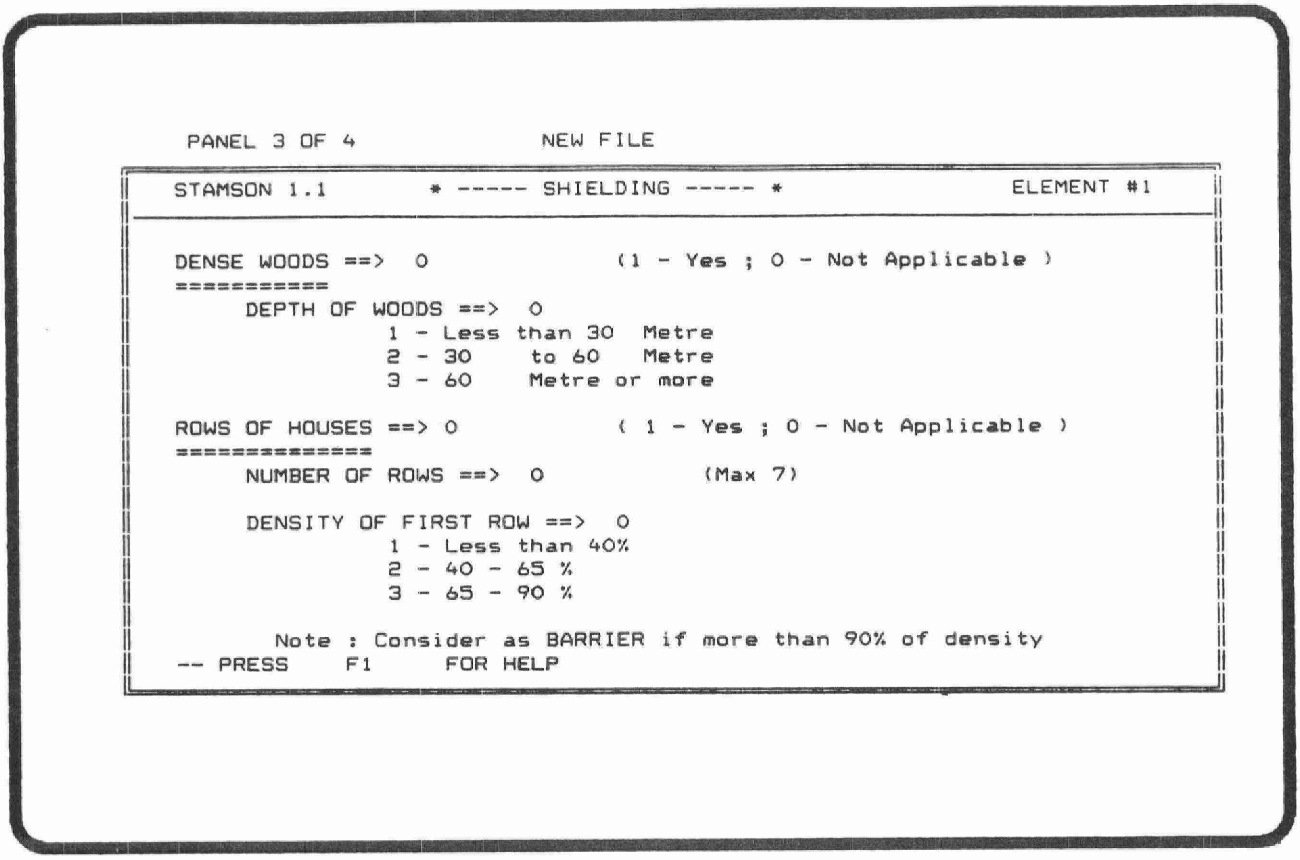
```
    PANEL 2 OF 4                NEW FILE

|| STAMSON 1.1    * ---------- TOPOGRAPHY & LAYOUT ---------- *  ELEMENT # 1  ||

||  ----------------------------------
|| |              ROADWAY             |  ROADWAY ELEMENT SIZE :
|| | -------------------------     _  |       ANGLE Θ1 ==>  -90  Degree
|| | -------------------------    /|\ |       ANGLE Θ2 ==>   90  Degree
|| | \           |           /     |  |
|| |   \         |         /       |  |
|| |     \  Θ1   |  Θ2   /         |  |  SOURCE-RECEIVER DISTANCE ==>  15.0Metre||
|| |       \     |     /         D |  |
|| |         \   |   /             |  |
|| |           \ | /              \|/ |  INTERMEDIATE GROUND SURFACE ==1
|| |             *                 -  |                        1 - ABSORPTIVE
|| |          RECEIVER                |                        2 - REFLECTIVE
|| | ---------------------------------|
||
||  HEIGHT OF RECEIVER ABOVE THE GROUND                ==>      0.0  Metre
||  ELEVATION OF ROADWAY (see help panel)              ==>      0.0  Metre
||     -- PRESS  F1  FOR HELP
```

HELP SCREEN



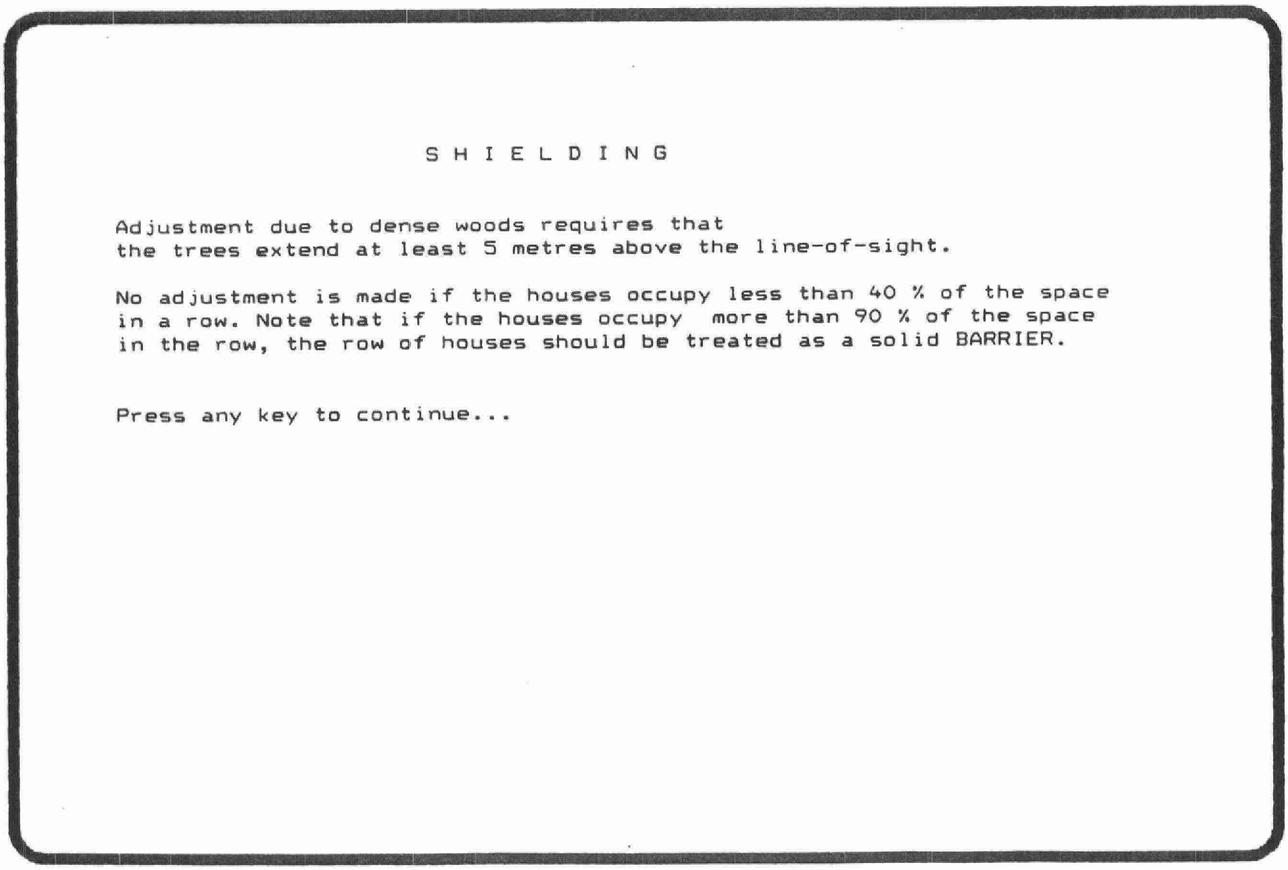
```
                 T O P O G R A P H Y   &   L A Y O U T


Angles must be in degrees.
Angle that lies to the left of the perpendicular line
from the receiver to the roadway must be entered as NEGATIVE.
Angle2 must be more greater than angle1.

The  receiver  ground  elevation is defined as the
ZERO REFERENCE ELEVATION.

The roadway elevation is relative to the receiver ground elevation.
The roadway elevation is POSITIVE if the roadway is above the receiver
ground elevation and NEGATIVE if the roadway is below the
receiver ground elevation.

The soũrce height and the receiver height are the heights
above the roadway and the receiver ground elevation, respectively.

The source height is calculated in the program based
upon the unadjusted percentage of heavy trucks.


Press any key to continue...
```

PROGRAM SCREEN



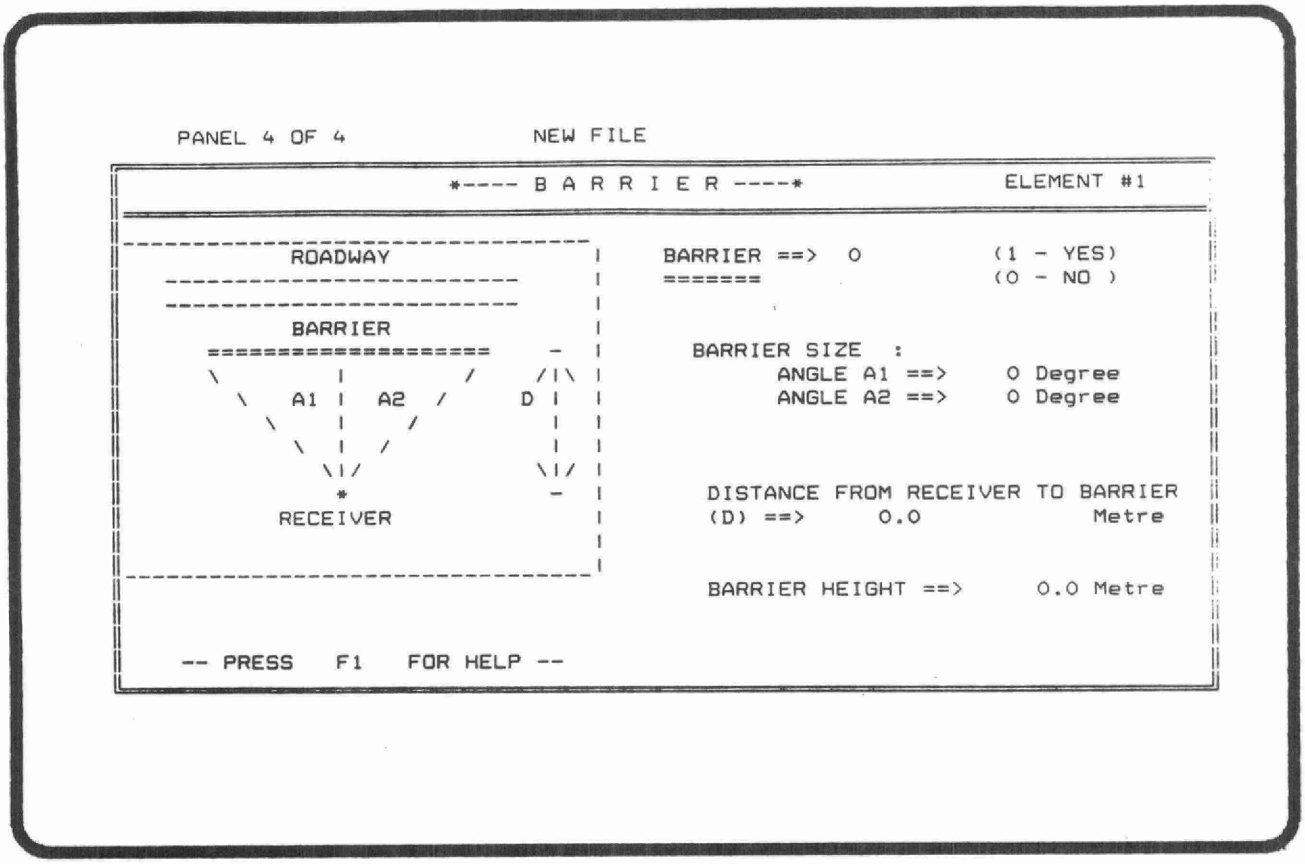
```
PANEL 3 OF 4              NEW FILE

STAMSON 1.1        * ----- SHIELDING ----- *                ELEMENT #1

DENSE WOODS ==>  0              (1 - Yes ; 0 - Not Applicable )
===========
     DEPTH OF WOODS ==>  0
               1 - Less than 30  Metre
               2 - 30     to 60   Metre
               3 - 60     Metre or more

ROWS OF HOUSES ==> 0            ( 1 - Yes ; 0 - Not Applicable )
==============
     NUMBER OF ROWS ==>  0           (Max 7)

     DENSITY OF FIRST ROW ==>  0
               1 - Less than 40%
               2 - 40 - 65 %
               3 - 65 - 90 %

       Note : Consider as BARRIER if more than 90% of density
-- PRESS    F1     FOR HELP
```

HELP SCREEN



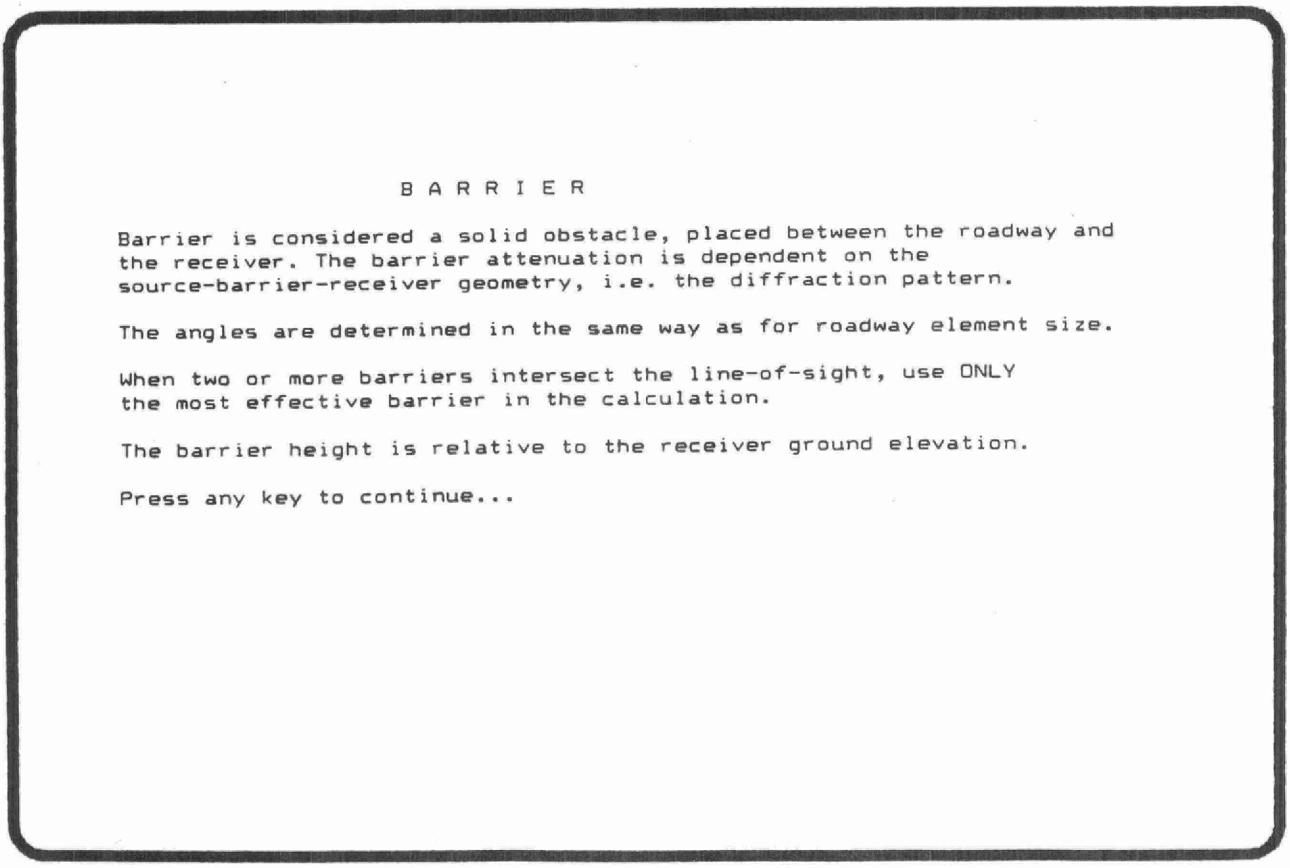
```
                    S H I E L D I N G


Adjustment due to dense woods requires that
the trees extend at least 5 metres above the line-of-sight.

No adjustment is made if the houses occupy less than 40 % of the space
in a row. Note that if the houses occupy  more than 90 % of the space
in the row, the row of houses should be treated as a solid BARRIER.


Press any key to continue...
```

PROGRAM SCREEN



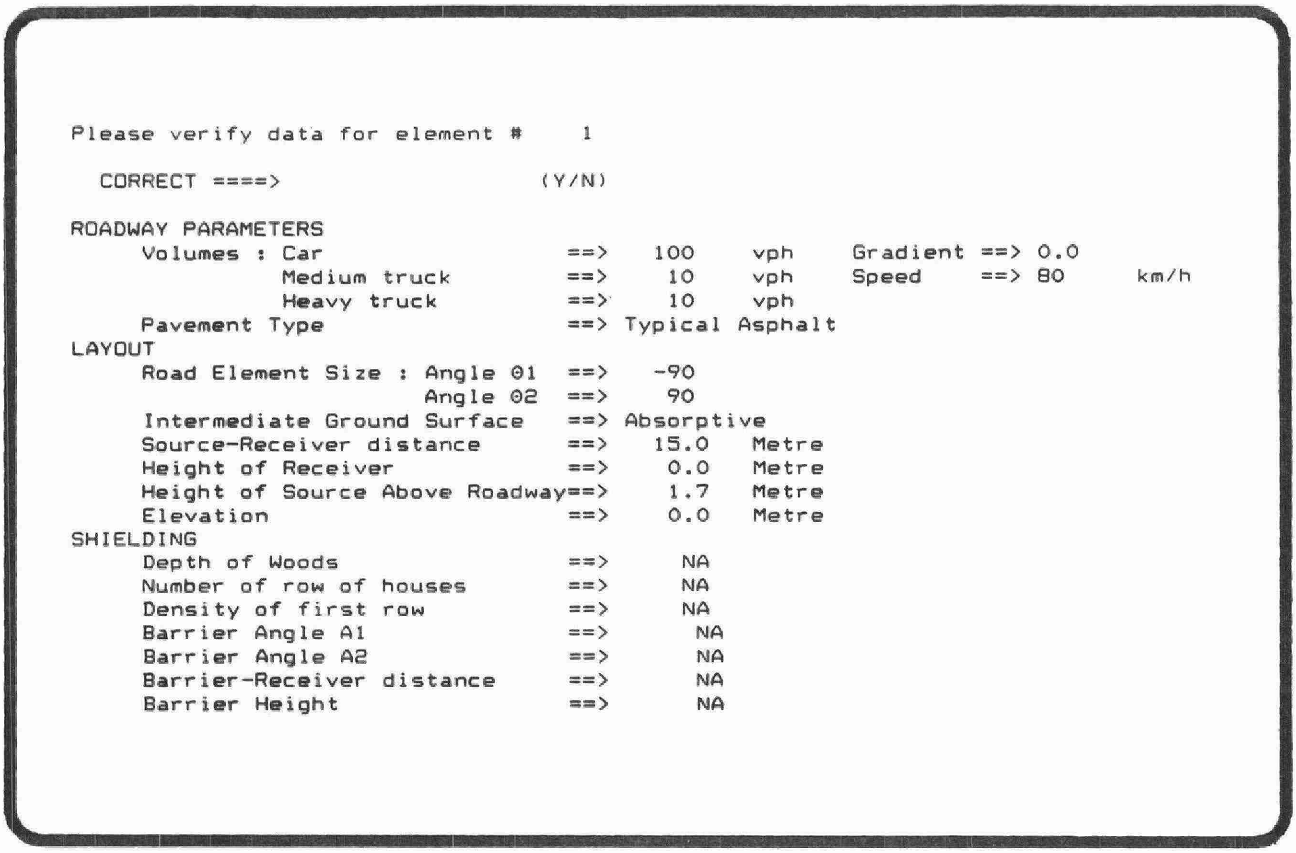
```
    PANEL 4 OF 4             NEW FILE

                       *---- B A R R I E R ----*               ELEMENT #1

----------------------------------
            ROADWAY               |    BARRIER ==>  0         (1 - YES)
   -------------------------      |    =======                (0 - NO )
   -------------------------      |
            BARRIER               |
      ====================     -  |      BARRIER SIZE   :
       \        |        /    /|\ |            ANGLE A1 ==>    0 Degree
         \  A1  | A2   /     D |  |            ANGLE A2 ==>    0 Degree
           \    |    /         |  |
             \  |  /           |  |
               \|/            \|/ |
                *              -  |       DISTANCE FROM RECEIVER TO BARRIER
           RECEIVER               |       (D) ==>     0.0            Metre
                                  |
----------------------------------|
                                          BARRIER HEIGHT ==>      0.0 Metre


     -- PRESS   F1   FOR HELP --
```

HELP SCREEN



```
                 B A R R I E R

Barrier is considered a solid obstacle, placed between the roadway and
the receiver. The barrier attenuation is dependent on the
source-barrier-receiver geometry, i.e. the diffraction pattern.

The angles are determined in the same way as for roadway element size.

When two or more barriers intersect the line-of-sight, use ONLY
the most effective barrier in the calculation.

The barrier height is relative to the receiver ground elevation.

Press any key to continue...
```

PROGRAM SCREEN



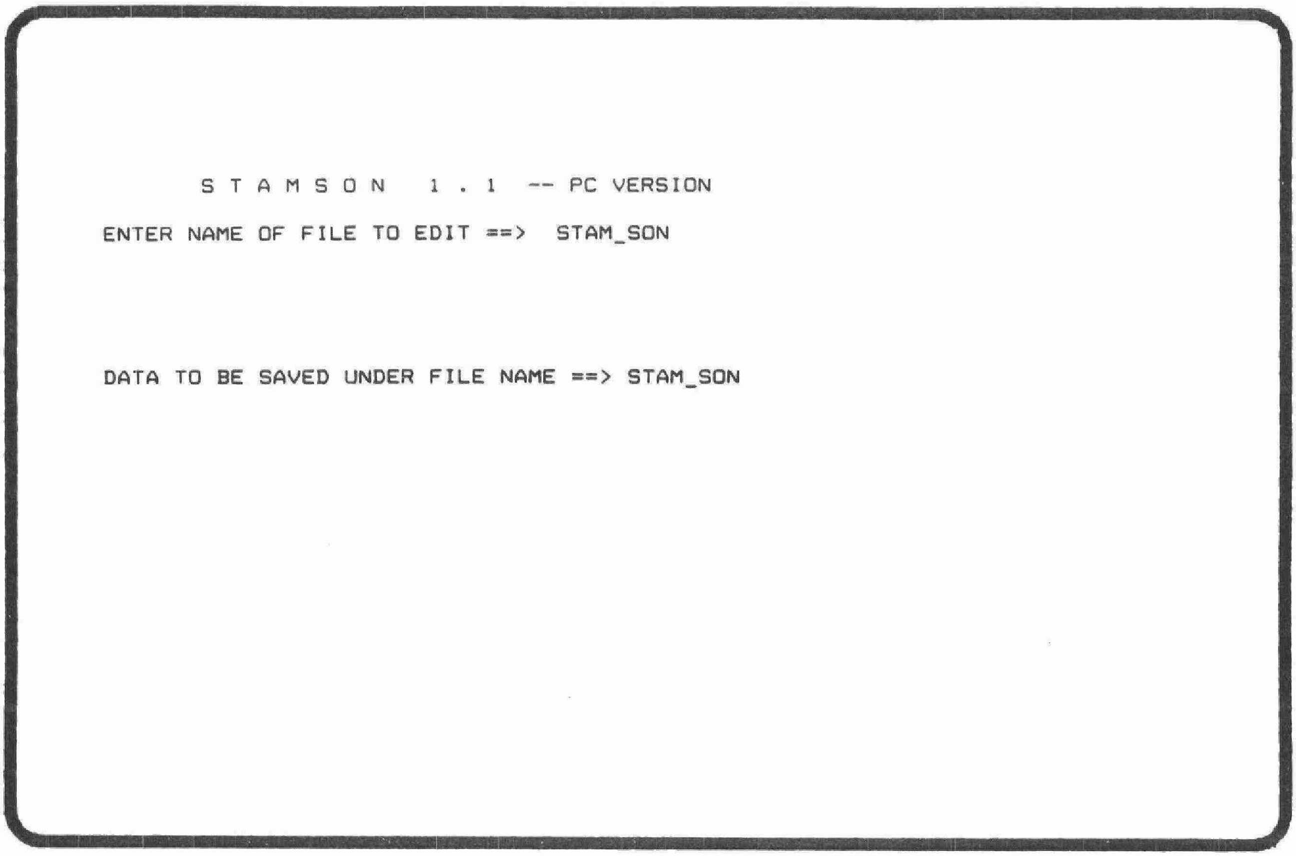
```
Please verify data for element #    1

  CORRECT ====>                   (Y/N)

ROADWAY PARAMETERS
     Volumes : Car                ==>   100    vph     Gradient ==> 0.0
               Medium truck       ==>    10    vph     Speed    ==> 80      km/h
               Heavy truck        ==>    10    vph
     Pavement Type                ==> Typical Asphalt
LAYOUT
     Road Element Size : Angle 01 ==>   -90
                         Angle 02 ==>    90
     Intermediate Ground Surface  ==> Absorptive
     Source-Receiver distance     ==>   15.0   Metre
     Height of Receiver           ==>    0.0   Metre
     Height of Source Above Roadway==>   1.7   Metre
     Elevation                    ==>    0.0   Metre
SHIELDING
     Depth of Woods               ==>    NA
     Number of row of houses      ==>    NA
     Density of first row         ==>    NA
     Barrier Angle A1             ==>     NA
     Barrier Angle A2             ==>     NA
     Barrier-Receiver distance    ==>     NA
     Barrier Height               ==>     NA
```

HELP SCREEN

MENU OPTION 2:

EDIT EXISTING FILE USING PANEL

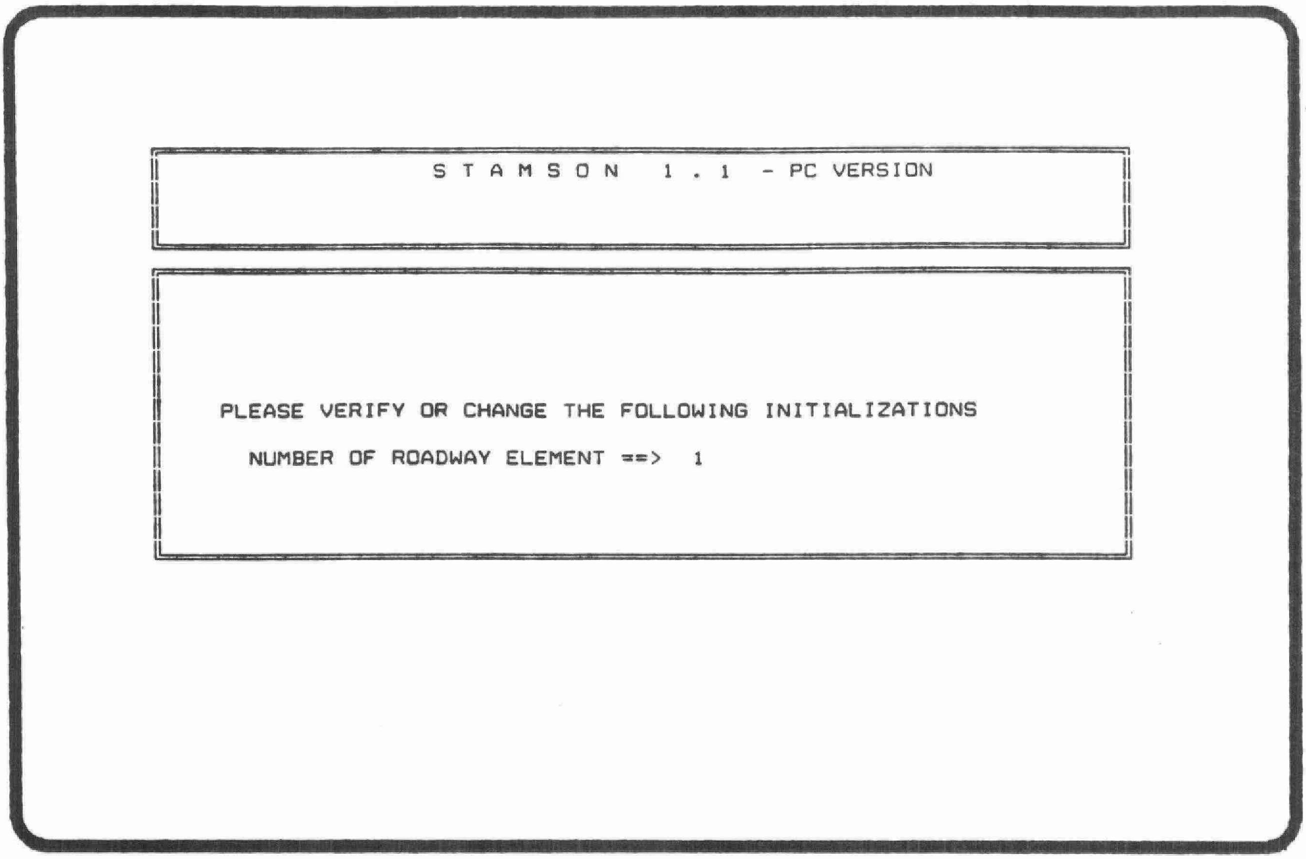
PROGRAM SCREEN



```
      S T A M S O N   1 . 1  -- PC VERSION

ENTER NAME OF FILE TO EDIT ==>  STAM_SON



DATA TO BE SAVED UNDER FILE NAME ==> STAM_SON
```

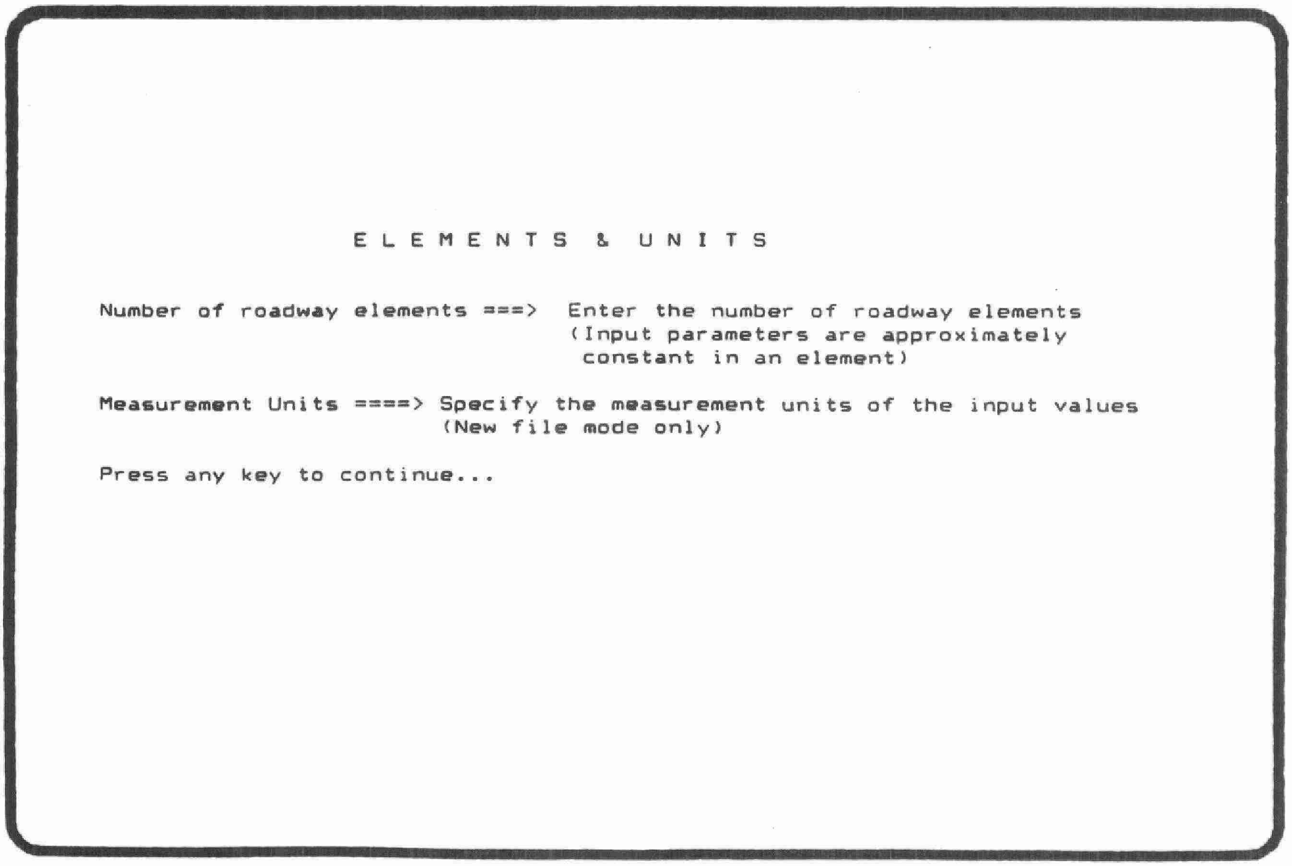
HELP SCREEN

PROGRAM SCREEN



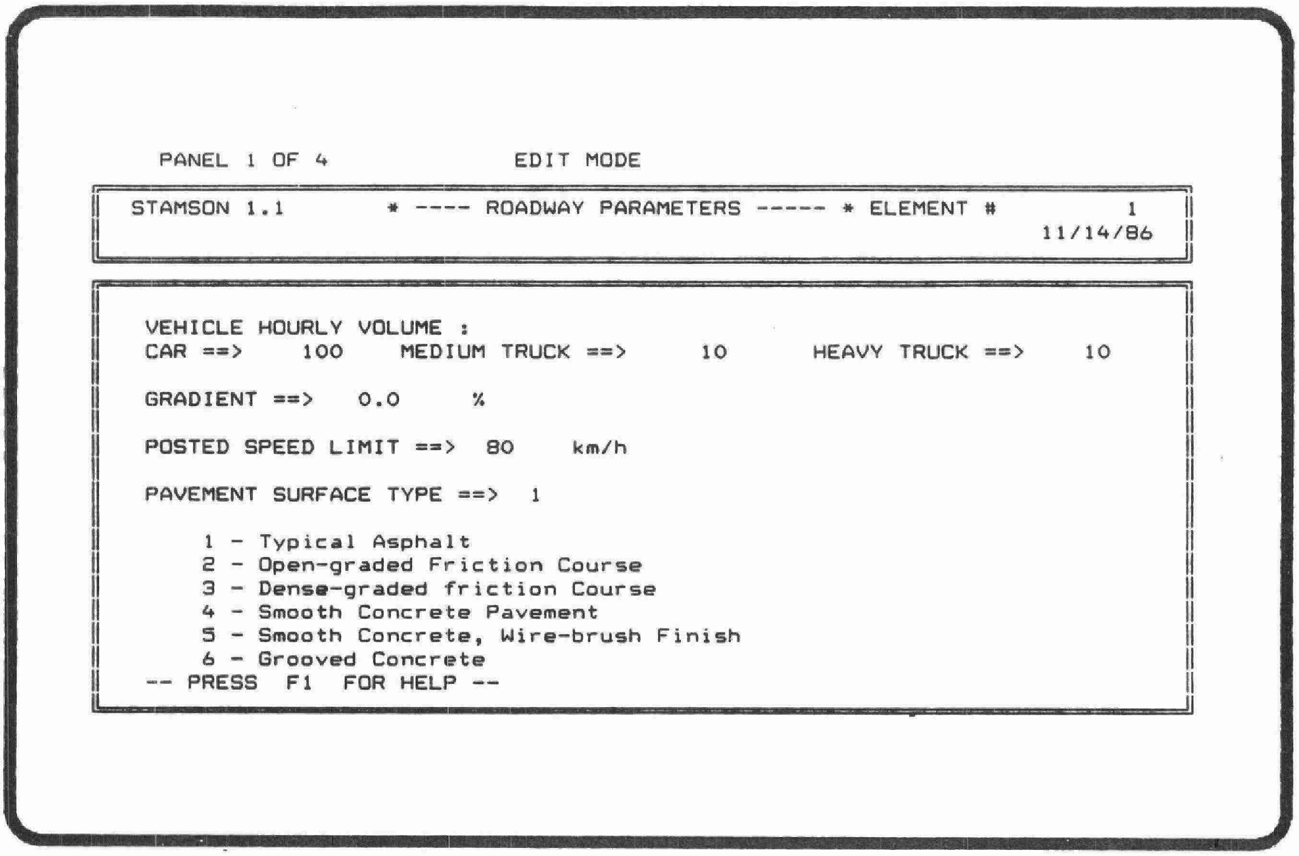
```
            S T A M S O N   1 . 1  - PC VERSION

  PLEASE VERIFY OR CHANGE THE FOLLOWING INITIALIZATIONS

    NUMBER OF ROADWAY ELEMENT ==>  1
```

HELP SCREEN



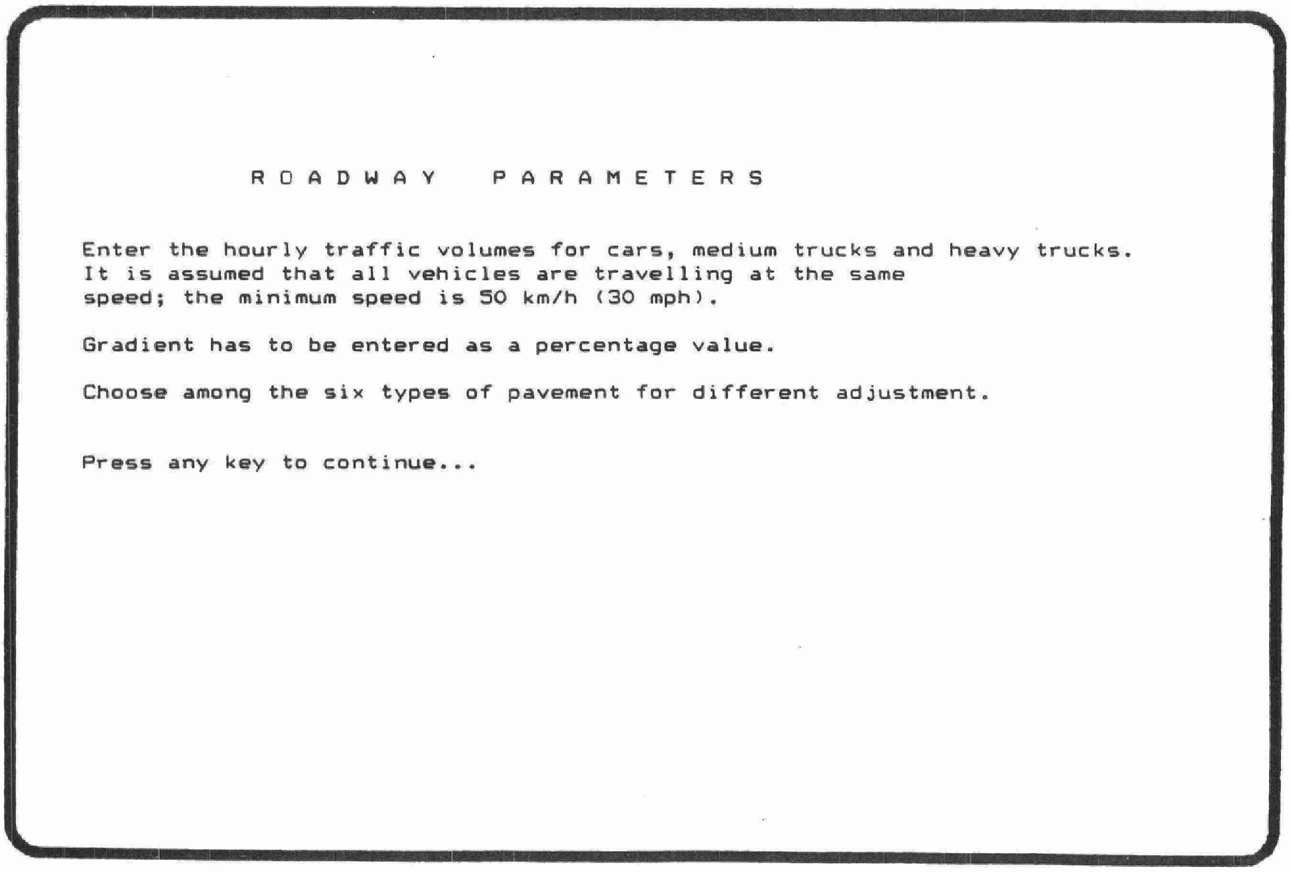
```
                E L E M E N T S  &  U N I T S

Number of roadway elements ===>  Enter the number of roadway elements
                                 (Input parameters are approximately
                                  constant in an element)

Measurement Units ====> Specify the measurement units of the input values
                        (New file mode only)

Press any key to continue...
```

PROGRAM SCREEN



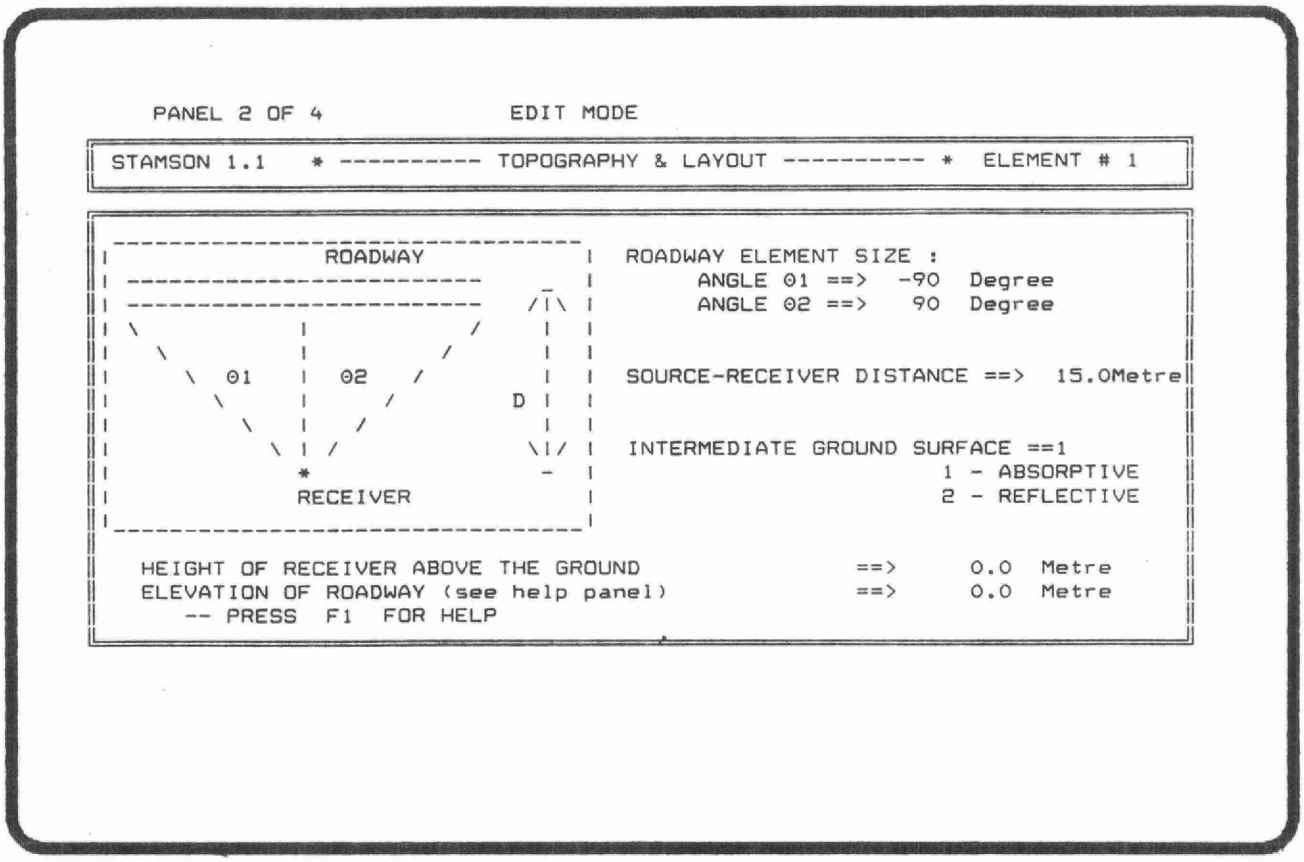
```
   PANEL  1  OF  4                  EDIT  MODE
 ╔═══════════════════════════════════════════════════════════════════════════╗
 ║ STAMSON 1.1        * ---- ROADWAY PARAMETERS ----- * ELEMENT #          1 ║
 ║                                                                   11/14/86 ║
 ╚═══════════════════════════════════════════════════════════════════════════╝
 ╔═══════════════════════════════════════════════════════════════════════════╗
 ║                                                                            ║
 ║   VEHICLE HOURLY VOLUME :                                                  ║
 ║   CAR ==>     100    MEDIUM TRUCK ==>      10      HEAVY TRUCK ==>    10   ║
 ║                                                                            ║
 ║   GRADIENT ==>   0.0     %                                                 ║
 ║                                                                            ║
 ║   POSTED SPEED LIMIT ==>  80    km/h                                       ║
 ║                                                                            ║
 ║   PAVEMENT SURFACE TYPE ==>  1                                             ║
 ║                                                                            ║
 ║       1 - Typical Asphalt                                                  ║
 ║       2 - Open-graded Friction Course                                      ║
 ║       3 - Dense-graded friction Course                                     ║
 ║       4 - Smooth Concrete Pavement                                         ║
 ║       5 - Smooth Concrete, Wire-brush Finish                               ║
 ║       6 - Grooved Concrete                                                 ║
 ║   -- PRESS  F1  FOR HELP --                                                ║
 ╚═══════════════════════════════════════════════════════════════════════════╝
```

HELP SCREEN



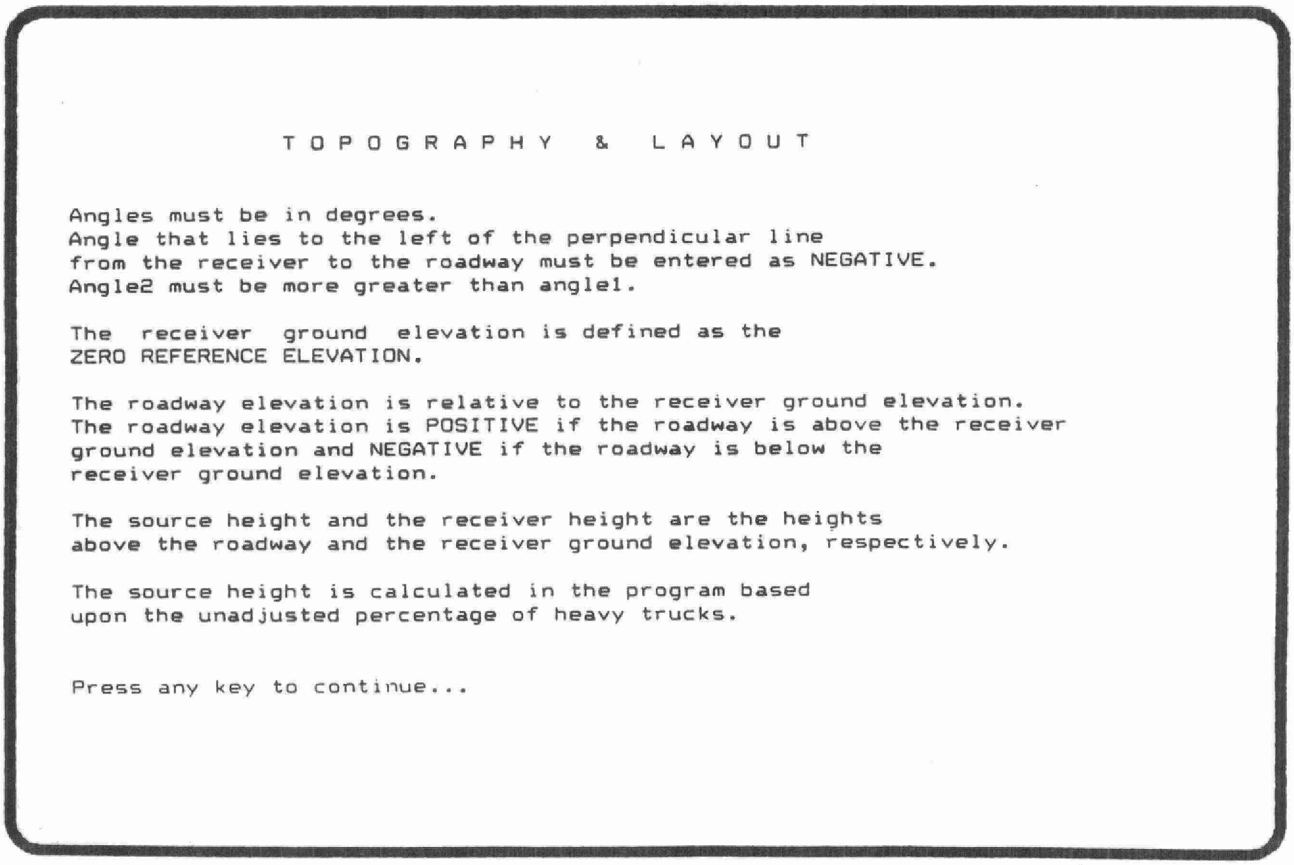
```
              R O A D W A Y    P A R A M E T E R S


Enter the hourly traffic volumes for cars, medium trucks and heavy trucks.
It is assumed that all vehicles are travelling at the same
speed; the minimum speed is 50 km/h (30 mph).

Gradient has to be entered as a percentage value.

Choose among the six types of pavement for different adjustment.


Press any key to continue...
```

PROGRAM SCREEN



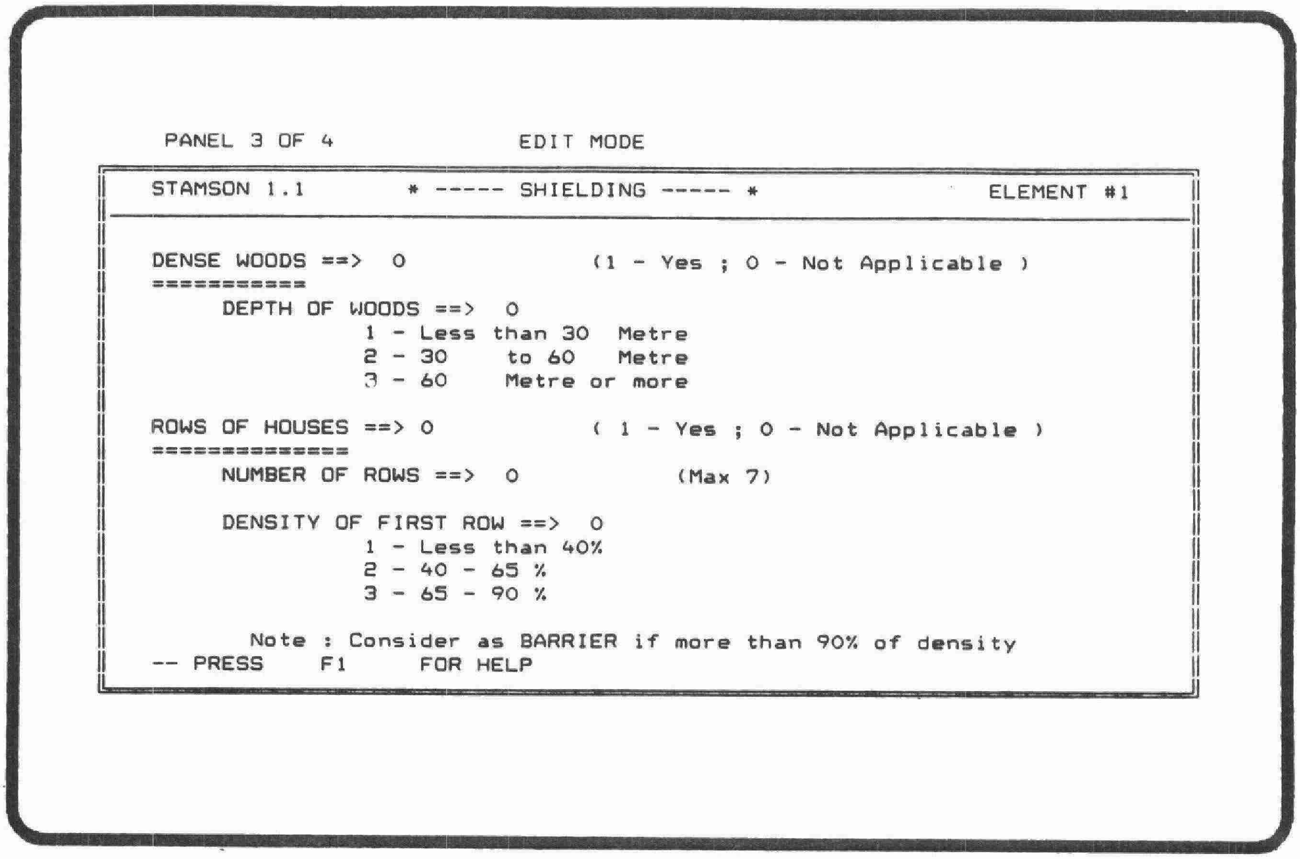
```
   PANEL 2 OF 4                EDIT MODE

 STAMSON 1.1   * ---------- TOPOGRAPHY & LAYOUT ---------- *  ELEMENT # 1

 ----------------------------------
|               ROADWAY            |  ROADWAY ELEMENT SIZE :
| --------------------------    _  |       ANGLE 01 ==>  -90  Degree
| --------------------------   /|\ |       ANGLE 02 ==>   90  Degree
| \           |            /    |  |
|   \         |          /      |  |
|     \  01   |  02    /        |  |  SOURCE-RECEIVER DISTANCE ==>  15.0Metre
|       \     |     /         D |  |
|         \   |   /             |  |
|           \ | /              \|/ |  INTERMEDIATE GROUND SURFACE ==1
|             *                 -  |                        1 - ABSORPTIVE
|             RECEIVER             |                        2 - REFLECTIVE
|----------------------------------|

   HEIGHT OF RECEIVER ABOVE THE GROUND                ==>     0.0   Metre
   ELEVATION OF ROADWAY (see help panel)              ==>     0.0   Metre
      -- PRESS  F1  FOR HELP
```

HELP SCREEN



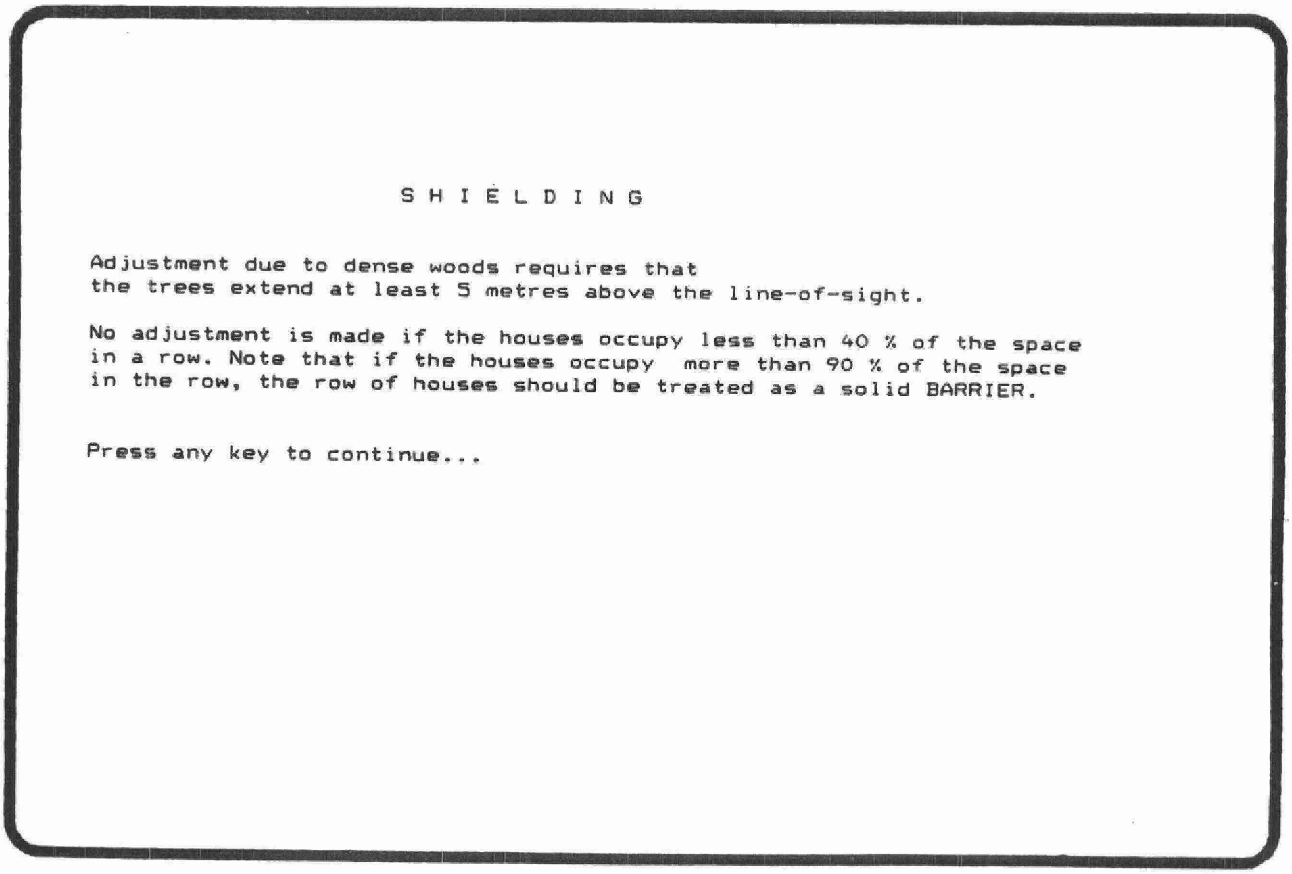
```
                T O P O G R A P H Y   &   L A Y O U T


Angles must be in degrees.
Angle that lies to the left of the perpendicular line
from the receiver to the roadway must be entered as NEGATIVE.
Angle2 must be more greater than angle1.

The  receiver  ground  elevation is defined as the
ZERO REFERENCE ELEVATION.

The roadway elevation is relative to the receiver ground elevation.
The roadway elevation is POSITIVE if the roadway is above the receiver
ground elevation and NEGATIVE if the roadway is below the
receiver ground elevation.

The source height and the receiver height are the heights
above the roadway and the receiver ground elevation, respectively.

The source height is calculated in the program based
upon the unadjusted percentage of heavy trucks.


Press any key to continue...
```

PROGRAM SCREEN



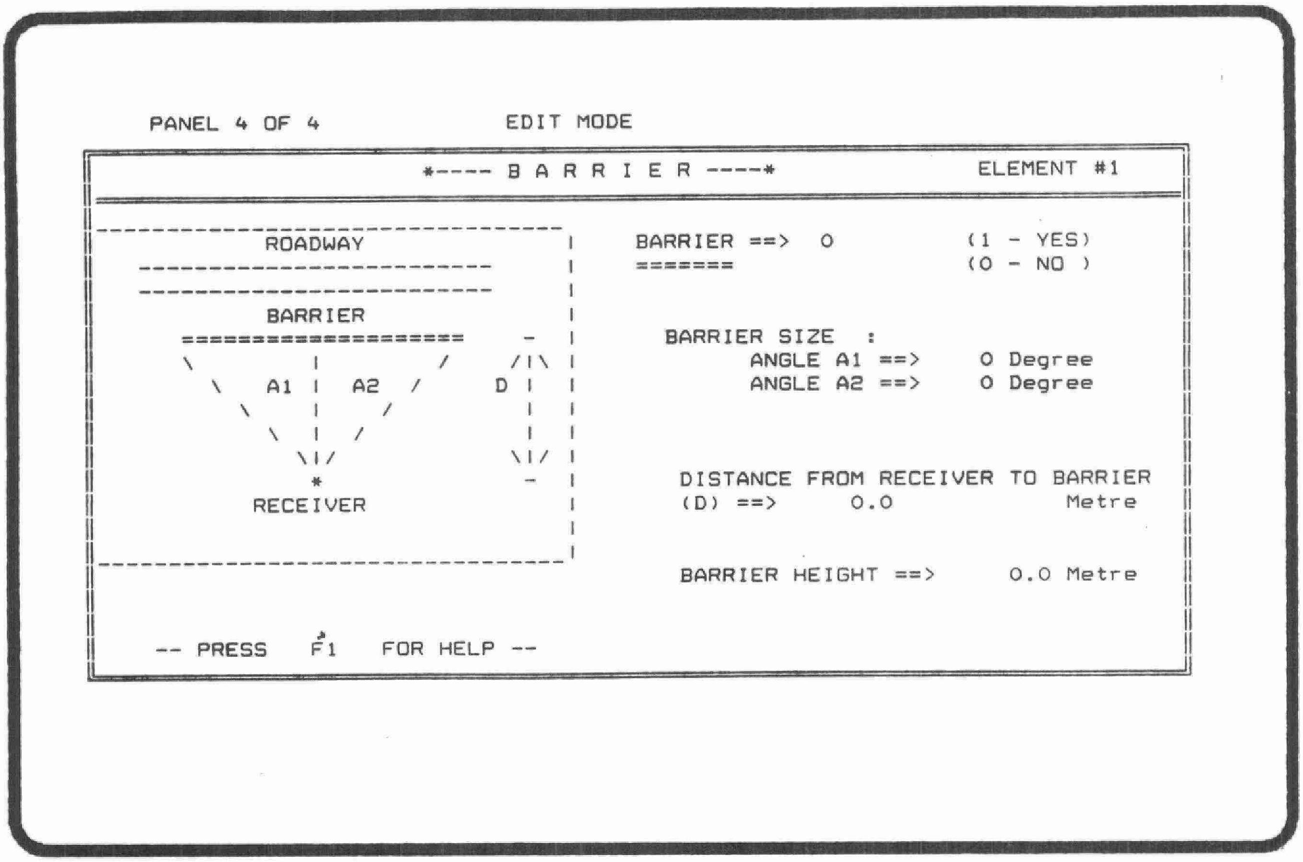
```
 PANEL 3 OF 4                 EDIT MODE

 STAMSON 1.1        * ----- SHIELDING ----- *              ELEMENT #1
 ------------------------------------------------------------------------

 DENSE WOODS ==>  0              (1 - Yes ; 0 - Not Applicable )
 ===========
      DEPTH OF WOODS ==>  0
                1 - Less than 30  Metre
                2 - 30    to 60   Metre
                3 - 60    Metre or more

 ROWS OF HOUSES ==> 0            ( 1 - Yes ; 0 - Not Applicable )
 ==============
      NUMBER OF ROWS ==>  0           (Max 7)

      DENSITY OF FIRST ROW ==>  0
                1 - Less than 40%
                2 - 40 - 65 %
                3 - 65 - 90 %

        Note : Consider as BARRIER if more than 90% of density
 -- PRESS    F1      FOR HELP
```

HELP SCREEN



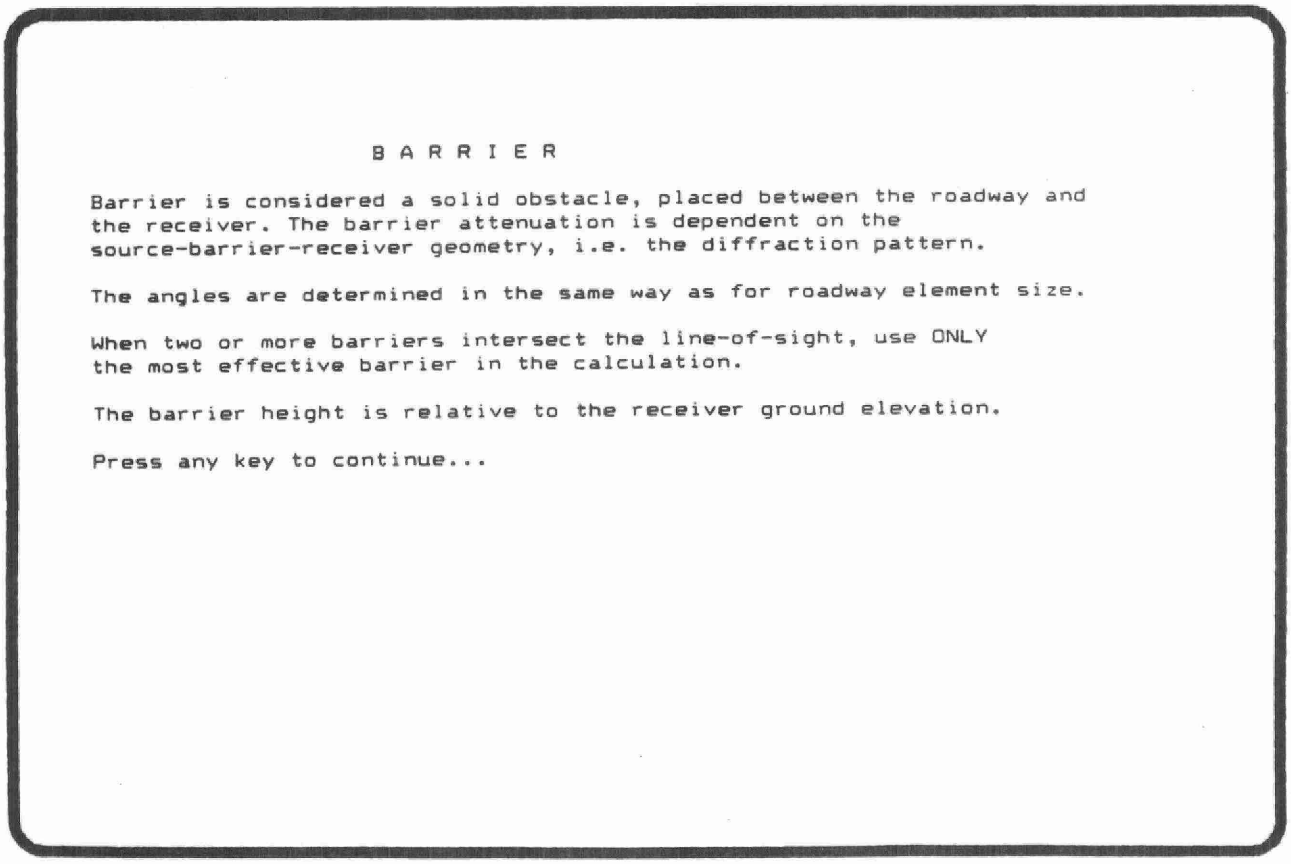
```
                      S H I E L D I N G

Adjustment due to dense woods requires that
the trees extend at least 5 metres above the line-of-sight.

No adjustment is made if the houses occupy less than 40 % of the space
in a row. Note that if the houses occupy  more than 90 % of the space
in the row, the row of houses should be treated as a solid BARRIER.


Press any key to continue...
```

PROGRAM SCREEN



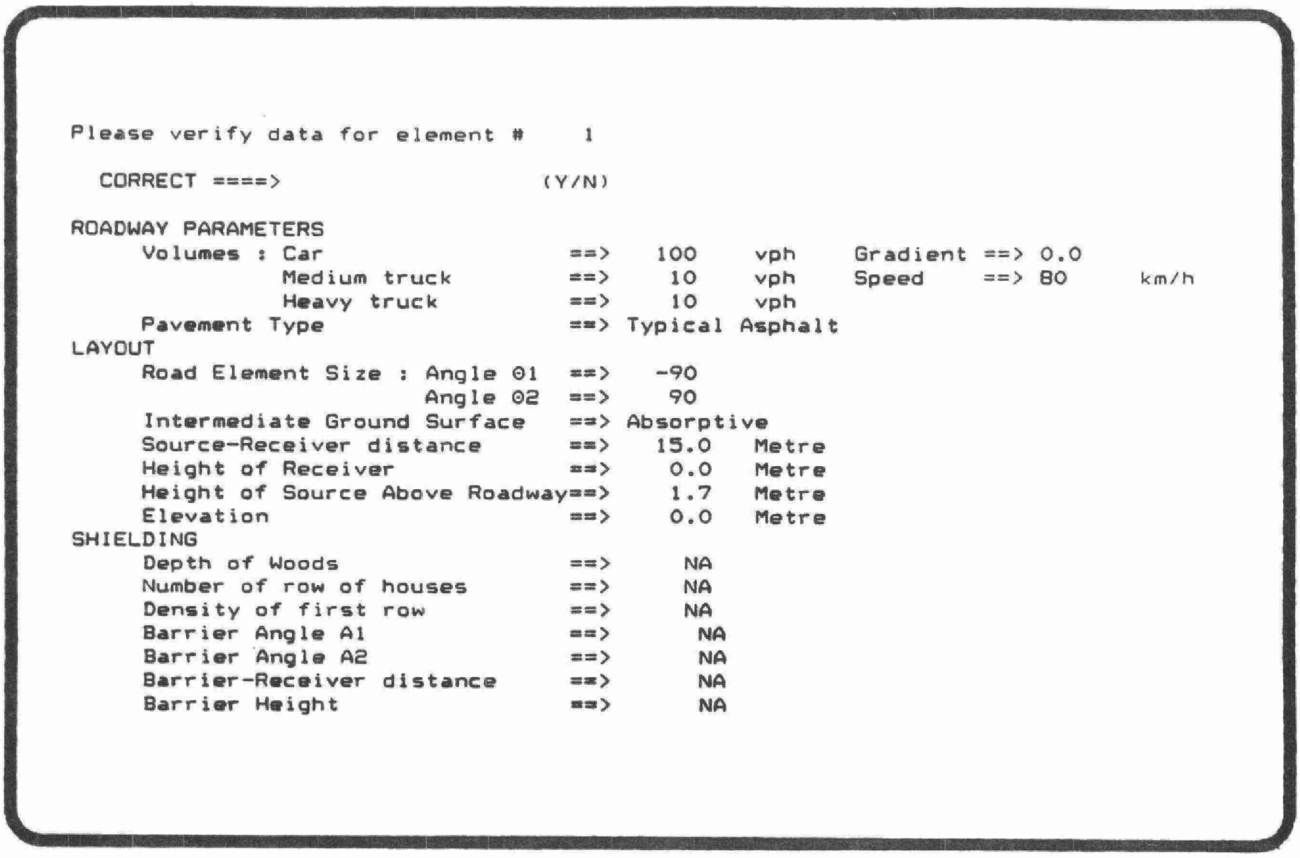
```
PANEL 4 OF 4                 EDIT MODE

                     *---- B A R R I E R ----*               ELEMENT #1
-------------------------------------
          ROADWAY                   |    BARRIER ==>  0            (1 - YES)
   --------------------------       |    =======                   (0 - NO )
   --------------------------       |
          BARRIER                   |
    ===================      -      |      BARRIER SIZE  :
    \         |         /   /|\     |            ANGLE A1 ==>     0 Degree
      \   A1  |  A2   /     D |     |            ANGLE A2 ==>     0 Degree
        \     |     /         |     |
          \   |   /           |     |
            \ | /            \|/    |
              *               -     |       DISTANCE FROM RECEIVER TO BARRIER
          RECEIVER                  |       (D) ==>      0.0             Metre
                                    |
-------------------------------------
                                            BARRIER HEIGHT ==>      0.0 Metre

    -- PRESS    F1    FOR HELP --
```

HELP SCREEN



```
                    B A R R I E R

Barrier is considered a solid obstacle, placed between the roadway and
the receiver. The barrier attenuation is dependent on the
source-barrier-receiver geometry, i.e. the diffraction pattern.

The angles are determined in the same way as for roadway element size.

When two or more barriers intersect the line-of-sight, use ONLY
the most effective barrier in the calculation.

The barrier height is relative to the receiver ground elevation.

Press any key to continue...
```

PROGRAM SCREEN



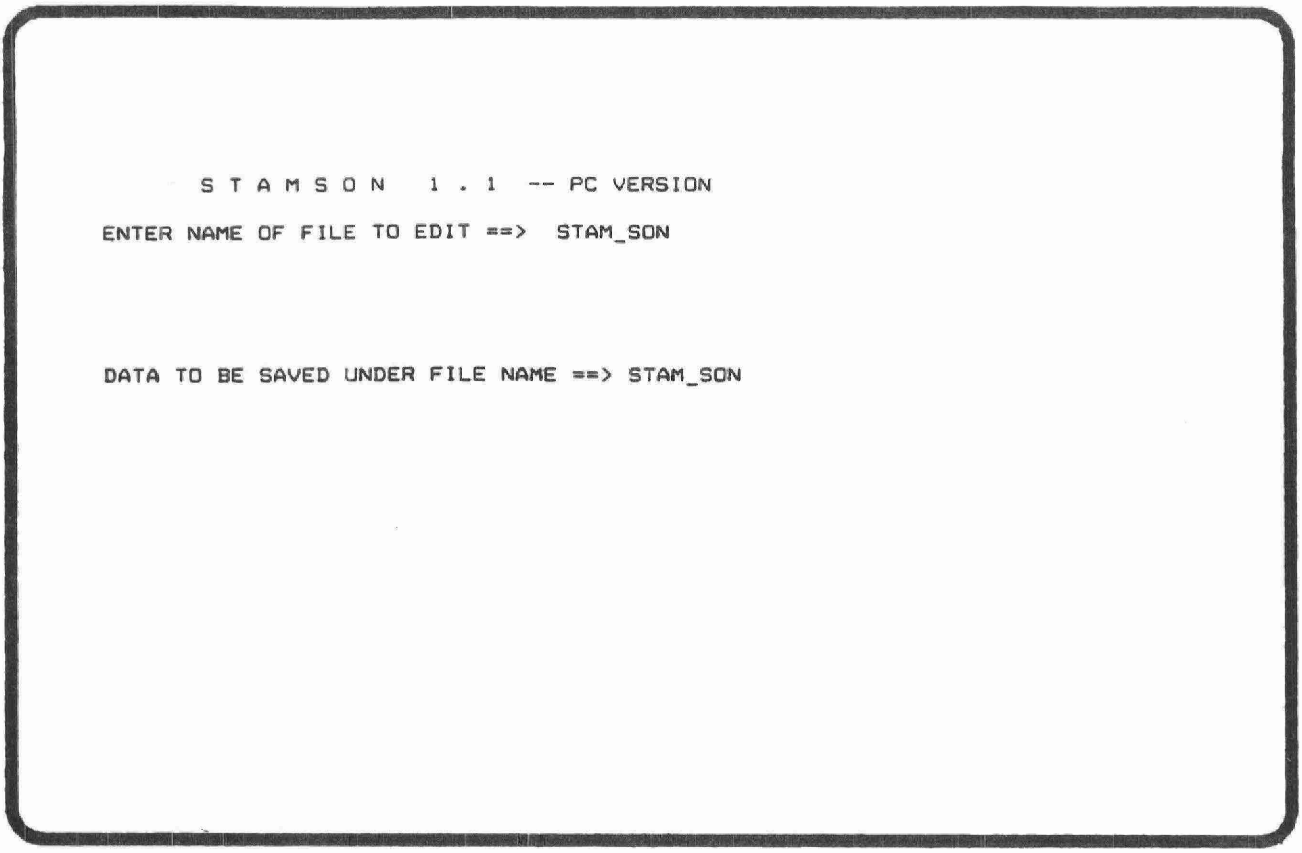
```
Please verify data for element #     1

  CORRECT ====>                     (Y/N)

ROADWAY PARAMETERS
     Volumes : Car                    ==>   100    vph    Gradient ==> 0.0
               Medium truck           ==>    10    vph    Speed    ==> 80      km/h
               Heavy truck            ==>    10    vph
     Pavement Type                    ==> Typical Asphalt
LAYOUT
     Road Element Size : Angle 01     ==>   -90
                         Angle 02     ==>    90
     Intermediate Ground Surface      ==> Absorptive
     Source-Receiver distance         ==>   15.0   Metre
     Height of Receiver               ==>    0.0   Metre
     Height of Source Above Roadway==>       1.7   Metre
     Elevation                        ==>    0.0   Metre
SHIELDING
     Depth of Woods                   ==>     NA
     Number of row of houses          ==>     NA
     Density of first row             ==>     NA
     Barrier Angle A1                 ==>      NA
     Barrier Angle A2                 ==>      NA
     Barrier-Receiver distance        ==>      NA
     Barrier Height                   ==>      NA
```

HELP SCREEN

MENU OPTION 3:

EDIT EXISTING FILE

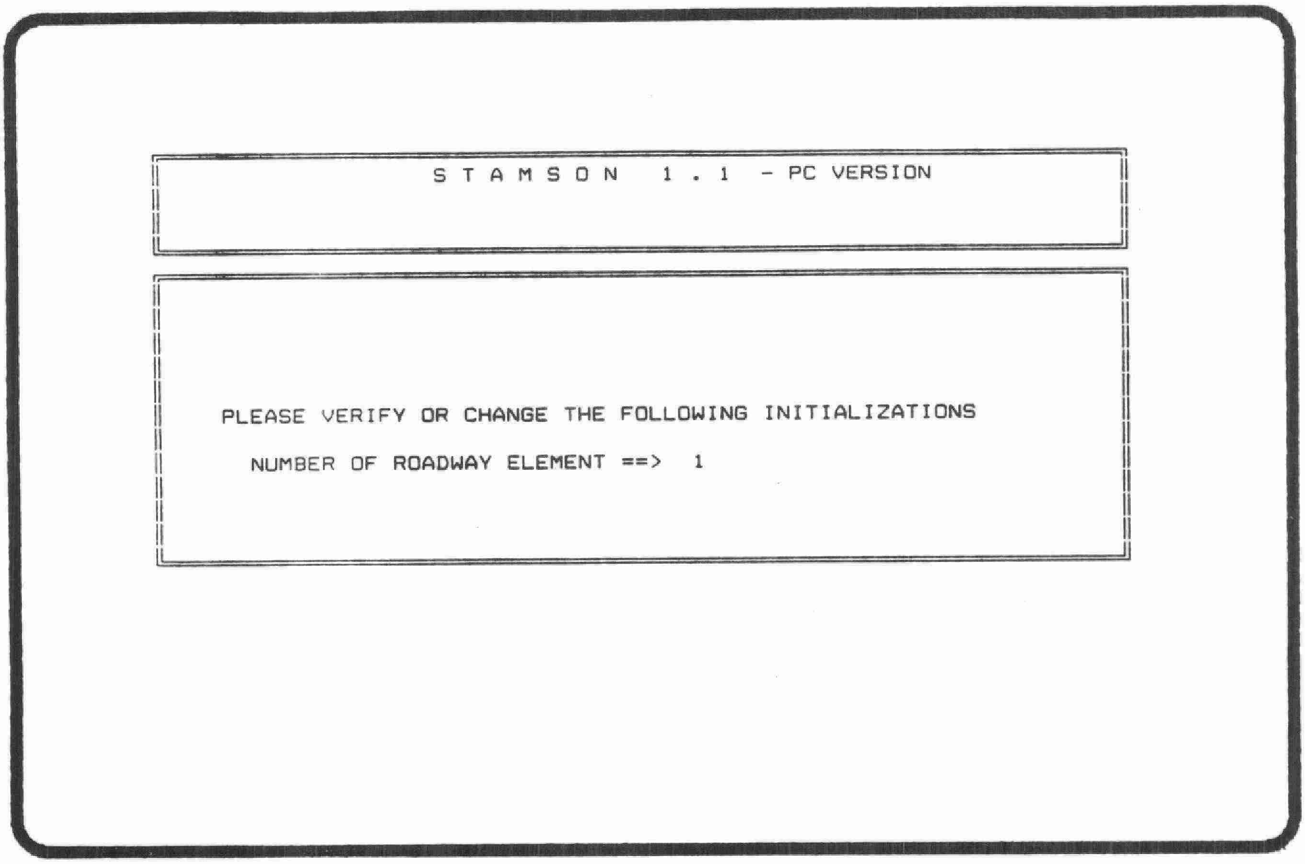
PROGRAM SCREEN



```
    S T A M S O N   1 . 1  -- PC VERSION
ENTER NAME OF FILE TO EDIT ==>  STAM_SON



DATA TO BE SAVED UNDER FILE NAME ==> STAM_SON
```

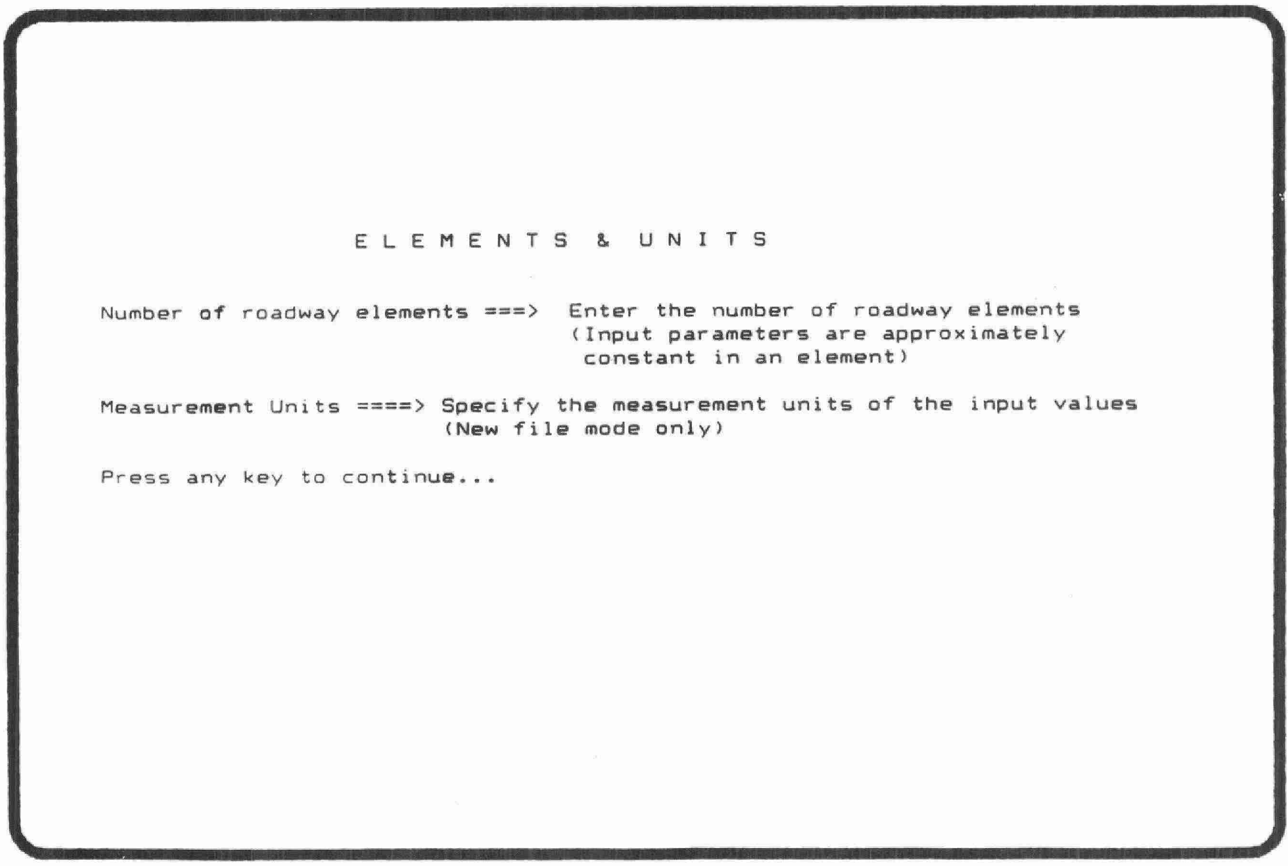
HELP SCREEN

PROGRAM SCREEN



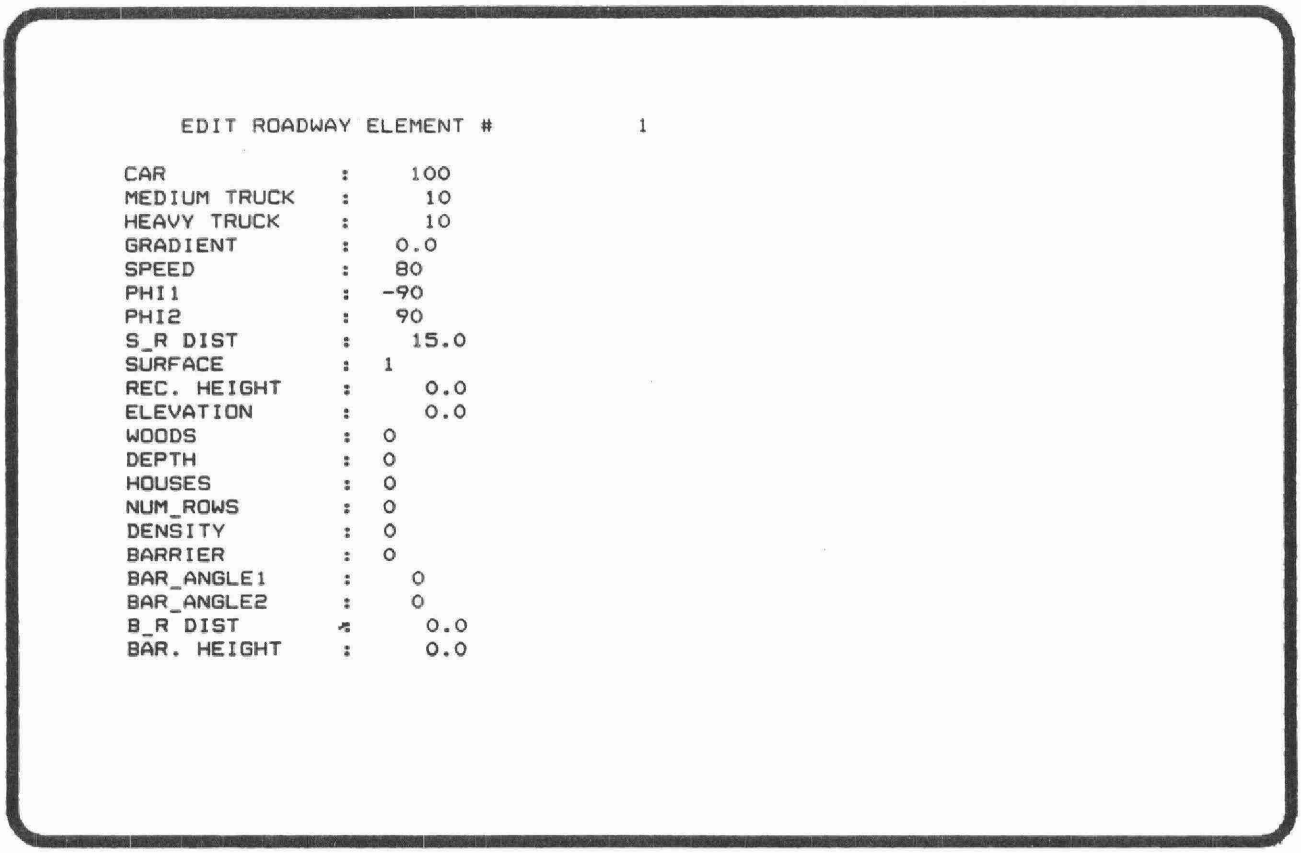
```
                    S T A M S O N   1 . 1   - PC VERSION



  PLEASE VERIFY OR CHANGE THE FOLLOWING INITIALIZATIONS

    NUMBER OF ROADWAY ELEMENT ==>   1
```

HELP SCREEN



```
                    E L E M E N T S   &   U N I T S

Number of roadway elements ===>  Enter the number of roadway elements
                                 (Input parameters are approximately
                                  constant in an element)

Measurement Units ====> Specify the measurement units of the input values
                        (New file mode only)

Press any key to continue...
```

PROGRAM SCREEN



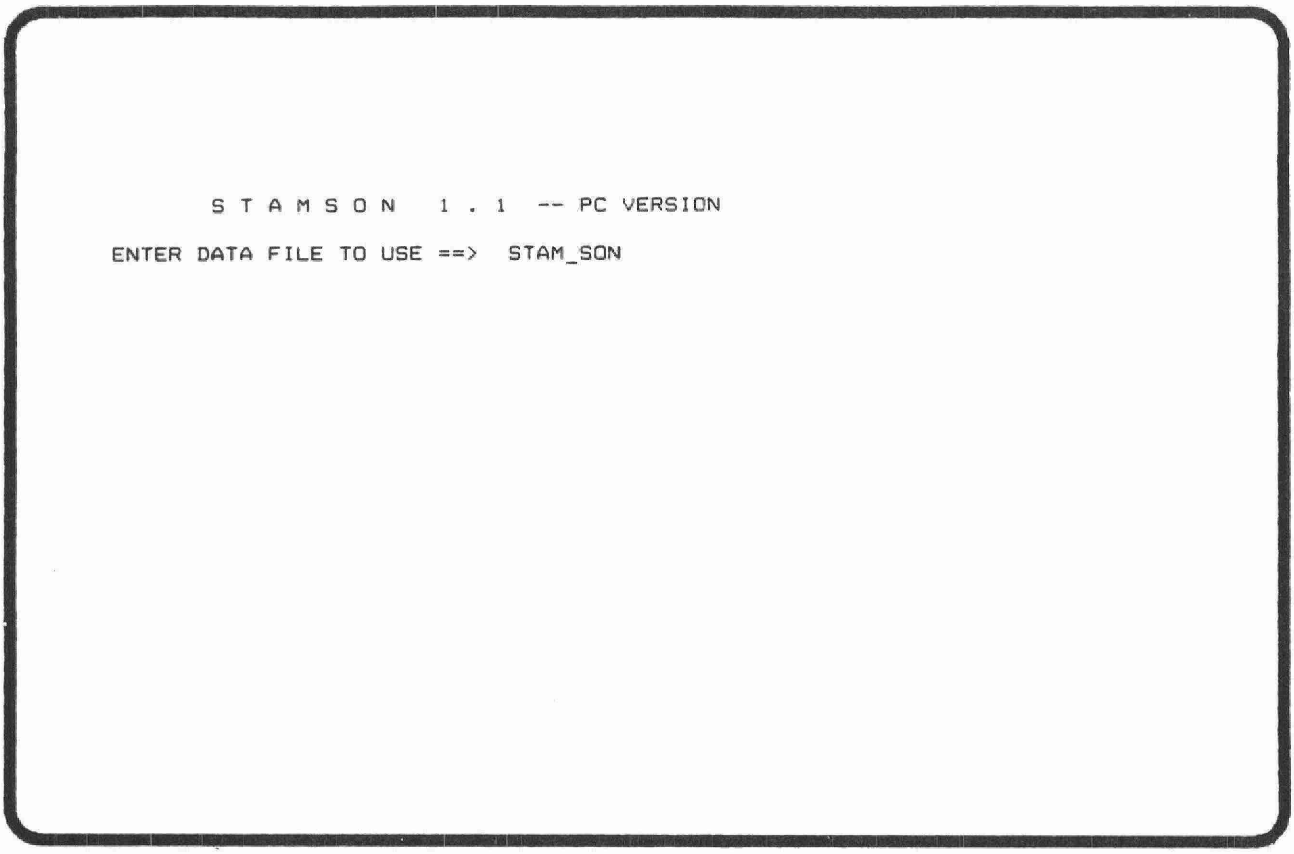
```
    EDIT ROADWAY ELEMENT #           1

CAR               :     100
MEDIUM TRUCK      :      10
HEAVY TRUCK       :      10
GRADIENT          :   0.0
SPEED             :   80
PHI1              :  -90
PHI2              :   90
S_R DIST          :     15.0
SURFACE           :  1
REC. HEIGHT       :      0.0
ELEVATION         :      0.0
WOODS             :  0
DEPTH             :  0
HOUSES            :  0
NUM_ROWS          :  0
DENSITY           :  0
BARRIER           :  0
BAR_ANGLE1        :    0
BAR_ANGLE2        :    0
B_R DIST          :      0.0
BAR. HEIGHT       :      0.0
```

HELP SCREEN

MENU OPTION 4:

RUN STAMSON

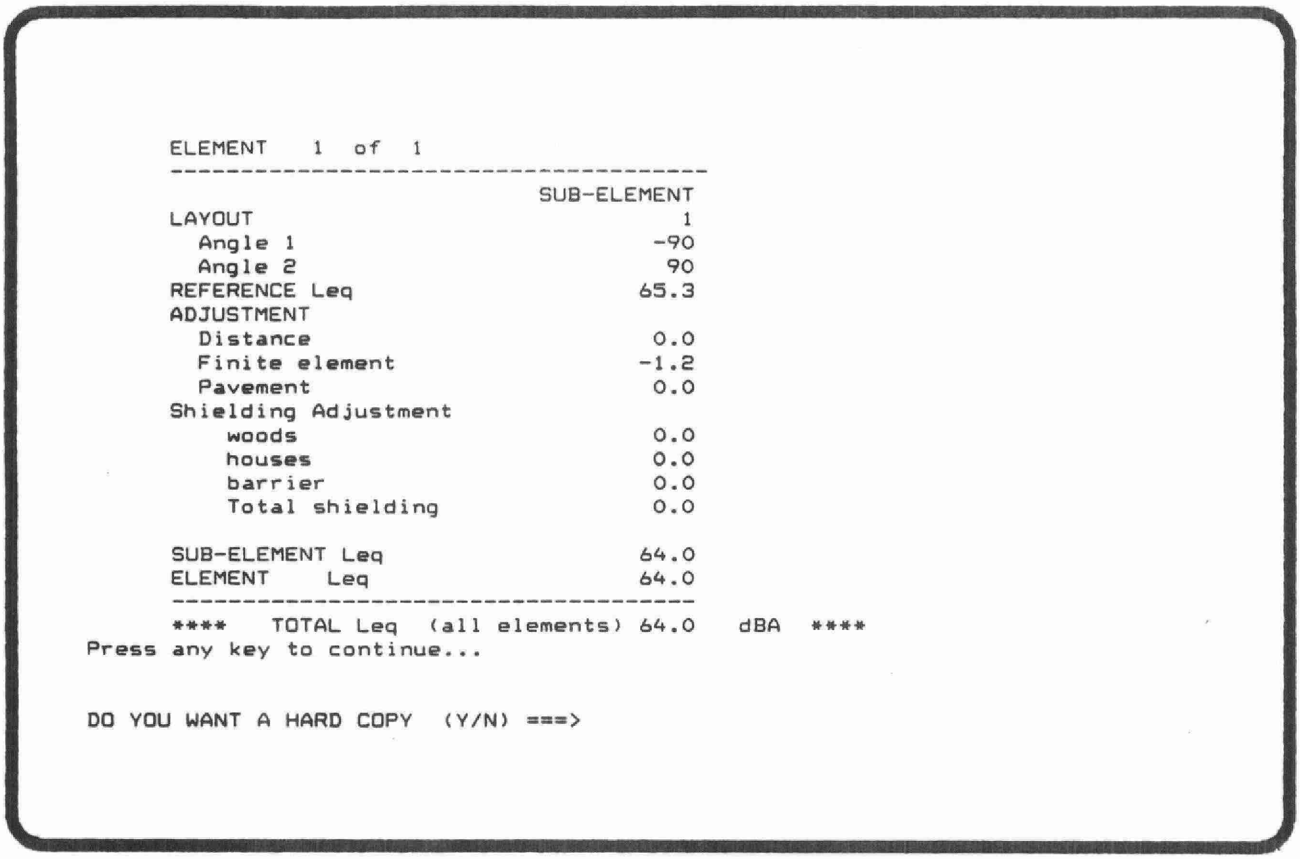
PROGRAM SCREEN



```
      S T A M S O N   1 . 1  -- PC VERSION
ENTER DATA FILE TO USE ==>  STAM_SON
```

HELP SCREEN

PROGRAM SCREEN



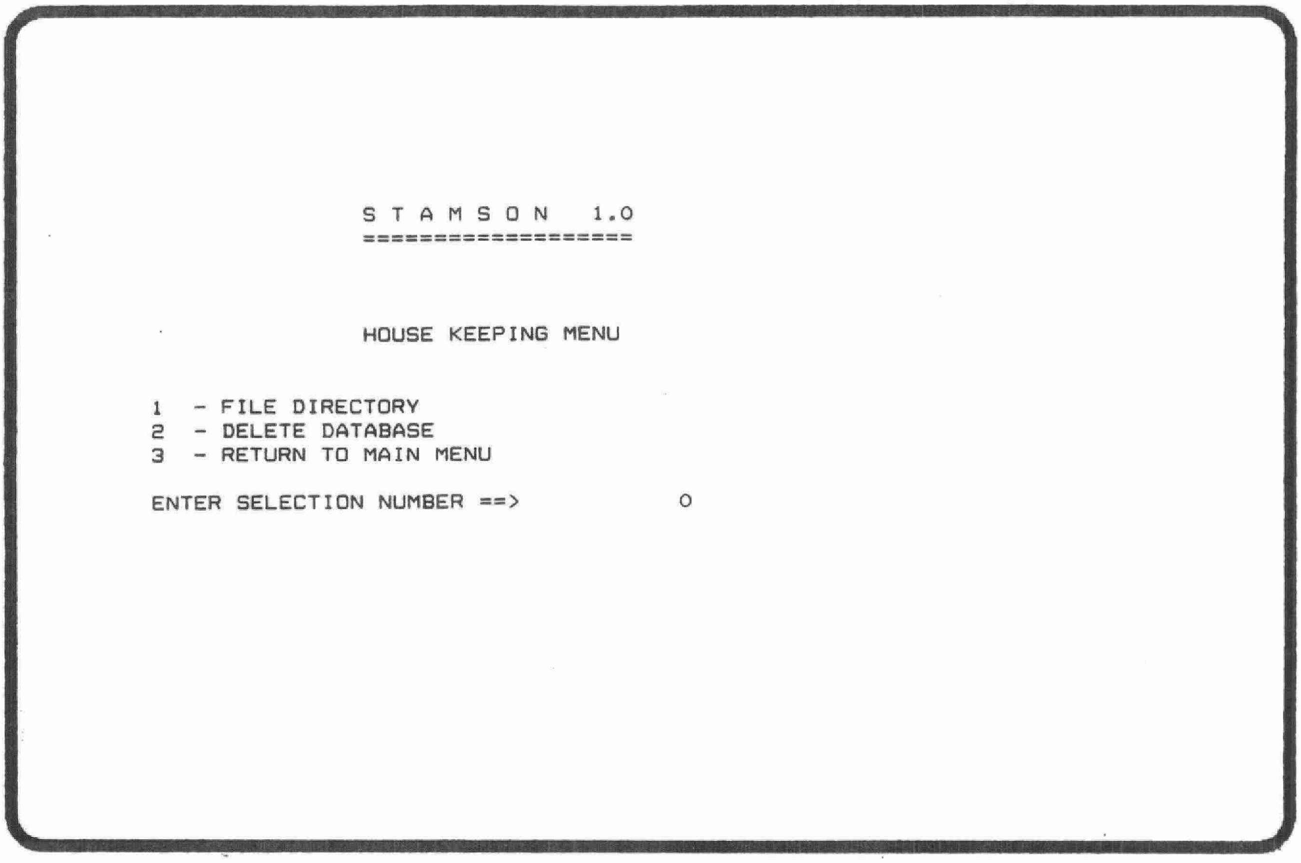
```
      ELEMENT    1  of   1
      --------------------------------------
                                 SUB-ELEMENT
      LAYOUT                               1
        Angle 1                          -90
        Angle 2                           90
      REFERENCE Leq                     65.3
      ADJUSTMENT
        Distance                         0.0
        Finite element                  -1.2
        Pavement                         0.0
      Shielding Adjustment
          woods                          0.0
          houses                         0.0
          barrier                        0.0
          Total shielding                0.0

      SUB-ELEMENT Leq                   64.0
      ELEMENT     Leq                   64.0
      -------------------------------------
      ****   TOTAL Leq  (all elements) 64.0    dBA   ****
Press any key to continue...

DO YOU WANT A HARD COPY  (Y/N) ===>
```

HELP SCREEN

MENU OPTION 5:

HOUSE KEEPING

PROGRAM SCREEN



```
               S T A M S O N   1.0
               ===================


               HOUSE KEEPING MENU


1  - FILE DIRECTORY
2  - DELETE DATABASE
3  - RETURN TO MAIN MENU

ENTER SELECTION NUMBER ==>           0
```

HELP SCREEN

APPENDIX F

BALCONY NOISE

Ministry
of the
Environment

Ministère
de
l'Environnement

ENVIRONMENTAL APPROVALS AND
LAND USE PLANNING BRANCH

135 St. Clair Avenue West
Suite 100
Toronto, Ontario
M4V 1P5

135 ouest, avenue St. Clai
Bureau 100
Toronto (Ontario)
M4V 1P5

965-3071

October 22, 1986

MEMORANDUM

TO: All Regional Directors

FROM: W.R. Balfour
Director

RE: BALCONY NOISE

Recently the issue of balcony noise and the mitigation methods were brought to our attention by Mr. L.W. Fitz of Southeastern Region (letter attached). The various concerns raised by Mr. Fitz were discussed in the Noise Assessment Unit. Our conclusions and position are outlined below.

The Noise Assessment Unit in the past had not taken a strong position to declare balconies as outdoor living areas for a variety of reasons. One of the main reasons is the difficulty of implementing required control measures as the Ministry's review takes place late in the process. In most cases, the building is already in place during the review as a result of the requirements placed on the developer by the "Condominium Act". In addition, if a balcony is enclosed due to noise excess, the developer may exceed the floor space limits. The "balconies" are therefore treated as storage area in many instances. This is somewhat reflected in the way balconies were not specifically mentioned in the Ministry publication NPC-131. However, the definition of "outdoor living areas" in the proposed ELUC policy (still in draft form) can be interpreted to include balconies.

The only other reference to balconies is made in the CMHC document "Road and Rail Noise: Effects on Housing" (NHA 5156 81/10). The following is reproduced from page 8 of the above document.

> "In downtown apartment projects where, because of site restrictions, adequate noise reduction measures are not always possible, it is recognized that noise levels above 55 dB do not make open space completely ineligible for inclusion as amenity space. To provide a flexible

> approach, a sliding scale may be used in which for each 2 dB over the acceptable limit, 10% of the area of a balcony or other open space is ineligible, e.g., a balcony of 30 m^2 with a level of 61 dB would have 21 m^2 eligible amenity area; at 65 dB the eligible area would be 15 m^2".

As you can see the procedure suggested by CMHC is not only vague, but also impractical.

All of the above concerns are taken into account into the following position used by the Noise Assessment Unit. Balconies are usually used for storage, fire exit, possible egress, etc. It is also recognized that the Ministry's review process is undertaken usually at a late stage. Balconies are then treated:

(i) Not as outdoor living areas if any of the following conditions exist:

- a) not part of the floor space.
- b) indoor/outdoor sheltered living areas for communal use are provided in the complex.
- c) if the depth is less than 4 m.

(ii) As outdoor living areas for all other cases.

No mitigation measures are required for case (i) and a Warning Clause registered on title would suffice. Mitigation measures are required for case (ii), but implementation difficulties must be borne in mind. Compromises may be worked out depending on the noise excess, implementation feasibilities at pre-planning stage, etc.

We hope the above position allows the effective and appropriate resolution of comments on developments with balconies.

W.R. Balfour

RR/mc

cc: D.P. Caplice
C.E. McIntyre
P. Joseph
L.G. Kende
I.B. Veitch

APPENDIX G

GUIDELINES FOR THE PREPARATION OF NOISE REPORTS

GENERAL GUIDELINES FOR THE PREPARATION OF ACOUSTICAL REPORTS IN THE REGION OF PEEL

1. INTRODUCTION

1.1 The Region of Peel and its constituent Area Municipalities require the applicants of all residential plans of subdivision, rezonings and site plans adjacent to major roads in the Region to engage the services of an acoustical specialist (hereafter referred to as the Acoustical Consultant) to prepare an acoustical report to be signed and submitted by a professional engineer or architect which will recommend noise control features to meet the noise level objectives of the Region of Peel, the Area Municipality and the Ministry of the Environment.

2. REPORT

2.1 Generally, an acoustical report for a plan of subdivision is required only prior to final approval of the plan to clear the conditions of draft approval. However, when a plan of subdivision has projected noise levels in excess of 65 dBA between 7 a.m. and 11 p.m., then an acoustical feasibility report will be required prior to draft approval to determine whether the design proposed and layout of the lots will allow the required noise attenuation levels to be achieved. (Five copies of the feasibility report are to be forwared to the Area Municipality with two additional copies to the Regional Planning Department when Regional roads or Provincial freeways are involved. The Area Municipality will circulate to the Ministry of the Environment only after the report is acceptable to the Area Municipality and the Region.)

2.2 The acoustical report must describe the plan of subdivision or the site and its relationship to the major roads and all other major noise sources including industrial, aircraft and rail noise, within 300 m of the proposed development. The report must identify all existing and future noise sources in consultation with the Area Municipality and Region of Peel. An outline for a typical report is attached as Appendix 1.

2.3 Aircraft and freeway noise shall be considered in accordance with Regional and Municipal Official Plan policies and the Ministry of Municipal Affairs' aircraft and freeway noise guidelines.

2.4 All other noise sources including industrial activity shall be considered in accordance with the Ministry of the Environment criteria and procedures.

2.5 The report shall give details of prediction techniques used to determine noise levels (roads, rail, aircraft) including all adjustments.

3. SOUND LEVEL LIMITS

3.1 The road traffic noise study will be based on the following criteria for sound level limits adopted by the Region of Peel, it's constituent Area Municipalities and the Ministry of the Environment:

3.2 Outdoor recreation (living) area

(7 am - 11 pm) Leq (16 hr) = 55 dBA
L50 (16 hr) = 52 dBA

outdoor area

(11 pm - 7 am) Leq (8 hr) = 50 dBA
L50 (8 hr) = 47 dBA

3.3 Indoor (bedrooms, hospitals)

(11 pm - 7 am) Leq (8 hr) = 40 dBA

3.4 Indoor (living rooms, hotels, private offices, reading rooms)

(7 am - 11 pm) Leq (16 hr) = 45 dBA

3.5 Indoor (general offices, shops)

(7 am - 11 pm) Leq (16 hr) = 50 dBA

4. TRAFFIC NOISE PREDICTIONS

4-1 With respect to Road Traffic Noise, only the prediction method accepted by the Ministry of the Environment may be used. (For details see the MOE Guidelines for Road Traffic Noise Assessment - July, 1986).

4.2 Traffic volumes on arterial roads in the Urban Area (used in predicting noise level calculations) must be based on ultimate lane configuration with level of service 'C' at posted speed limit, as set out in the table below:

Number of Lanes	AADT	% MEDIUM TRUCKS	% HEAVY TRUCKS
4 lanes	27 000*	Truck percentages are to be determined from actual counts, or obtained from municipal records where available.	
6 lanes	40 000*		

*(These volumes have been estimated for Level of Service 'C'. For collector type roads the Area Municipality should be consulted for appropriate volumes and truck percentages.)

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4.3 For traffic volumes in the rural area or on other types of roads, the appropriate road authority should be consulted by request in writing.

4.4 All traffic data should be supported by a letter from the road authority, included as an appendix to the report.

4.5 Predicted noise level calculations will be required for both daytime (7 a.m. - 11 p.m.) and nighttime (11 p.m. - 7 a.m.) periods.

4.6 If manual calculations are used, the report must contain the fully completed MOE Traffic Noise Prediction Work Sheet for all sections calculated.

If the MOE Noise Prediction Computer Model (Stamson 1) is used, the report must include a copy of the computer printout for all sections calculated.

4.7 The report must detail information on all adjustments where applicable.

4.8 Where there is more than one noise source impacting the plan, the calculation of the combined noise levels is required.

4.9 For industrial, aircraft, and rail sound level predictions, the Ministry of the Environment standard procedure methods should be employed with the report detailing the method of calculation.

5. NOISE BARRIER CALCULATIONS

5.1 In addition to noise level calculations, acoustical barrier calculations must also be included in the report and be accompanied by diagrams which must comply with the following criteria:

5.2 - typical and all worst case cross sections (and additional cross sections as may be necessary) at a vertical and horizontal scale of 1 to 50 (or 1 to 100) must be provided to clearly illustrate the proposed berm and wall configuration in relation to the future grade at the house. (Existing grades at the site should also be indicated.) Cross sections must include elevation of the noise source (HS), elevation of the receiver (HR), top elevation of the noise barrier (HB), ground elevation of the berm, berm slopes, sidewalks, boulevards, ditches, roadway elevations and property limits of the lands in question. Cross sections must provide all information required to calculate the path length difference (PLD); namely H_S, H_B, H_R, D_{SB} and D_{BR}. (See diagram 'A' in Appendix 1.)

5.3 - the location of the cross sections must be indicated on an attached copy of the preliminary grading plan. Preliminary grading plan should identify and make reference to all information shown on the cross sections (Roadway elevations, ground elevation at noise receivers, ground and top elevations of the berm, elevations of the rear yards, sidewalks, ditches, boulevards, etc.).

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5.4 - height of noise source is to be determined in accordance with the MOE Guidelines - July, 1986, (Table 8).

5.5 - height of noise receiver to be used is 1.5 m above the ground at a point located 3.0 m from the rear wall of the dwelling unit.

5.6 - barrier wall (i.e. fence) shall not exceed 2.0 m in height unless approved by the area municipality in consultation with appropriate road authority.

5.7 - a minimum of 4.0 m depth of rear yard as measured from rear face of the building will be required which contains no slope in excess of 2% in the City of Mississauga and 6.0 m in the City of Brampton and the Town of Caledon.

5.8 - a maximum slope of 3:1 in Mississauga and 4:1 in Brampton and Caledon will be required for any earth-work (i.e. berm) adjacent to the boulevard. Slopes steeper than 3:1 will be tolerated on the lot side of the earthwork by the use of retaining walls, etc. provided the Area Municipality is satisfied from a drainage and landscaping standpoint. (The 3:1 and 4:1 ratios may only be modified at the discretion of the Area Municipality).

5.9 - in cases where the attenuation facility is interrupted, barrier returns are required and the detailed design and calculations of the treatment in such cases will have to be incorporated into the acoustical report. The report must include a detailed plan and appropriate cross sections of such cases.

5.10 - barrier walls should generally be located no further than 0.3m in from the rear lot line or as specified by the Area Municipality.

5.11 - the maximum height of berm allowed is to be determined by the Area Municipality in consultation with appropriate road authority.

5.12 - the maximum height of berm/barrier allowed is to be determined in each case by the Area Municipality.

5.13 Information on acoustical barriers, berms, berm/wall combinations must include location and height of the barriers relative to a fixed point, namely centre line of the road.

5.14 Type and surface density of barrier should be specified.

5.15 The report shall be required to prove to the satisfaction of the Region of Peel, the Area Municipality and the Ministry of the Environment that the noise level in outdoor recreational areas after applying attenuation measures is the lowest level esthetically, technically, administratively and economically practical. To this end, the report shall provide a table of alternative berm and wall combination heights with resulting noise attenuating values for final selection of the Municipality. The base reference figure is to be 55 dBA. (See Table 1 of Appendix 1).

(Note: It is preferable, that where possible residential developments be designed such that the need for barrier type attenuation features, to control outdoor noise levels, is minimized.)

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6. OTHER NOISE CONTROL MEASURES FOR OUTDOOR AREAS

6.1 Alternative measures (site planning, service road, special type or location of acoustical barriers, etc.) should be discussed with the Region and the Area Municipality in advance to receive their acceptance in principle.

6.2 Front yard attenuation, (i.e. outdoor recreation areas in the front yard) are not an acceptable form of noise attenuation for reversed frontage lots.

7. NOISE ATTENUATION FOR INDOOR AREAS

7.1 Central air conditioning is required when the nightime noise level exceeds 60 dBA at the outside wall, second storey.

7.2. If central air conditioning is required, a noise insensitive location or other appropriate means of noise attenuation of the air cooled condenser unit should be stipulated in the report and specified in the subdivision agreement. If a heat pump is installed, the location of the outdoor unit should be specified as well.

7.3 If the nightime outer noise level is above 50 dBA and not greater than 60 dBA forced air heating is to be installed with provision for central air conditioning and a warning clause note to this effect is to be included in the report and in the subdivision agreement for registration on title. (See wording in item 8.)

7.4 Window glazing is to be specified either as pane thickness and air gap or minimum STC/AIF rating, if the nightime outer noise level at window is 60 dBA or greater. All recommendations shall comply with the Ontario Building Code and local regulations.

7.5 Outer wall specifications are to be determined and listed in the report for inclusion in the subdivision agreement, if the nightime outer noise level is 60 dBA or greater.

7.6 In cases of high noise levels (60 dBA and over) door specifications are also required.

8. WARNING CLAUSES

8.1 The following minimum wording is to be used in the Subdivision Agreement and in all offers of purchase and sale and is to be registered on title (for the specific lots) when noise levels are not being attenuated and the levels exceed the Municipality's and the Ministry of the Environment's noise criteria, but do not exceed the criteria by more than 5 dBA:

"Purchasers are advised that noise levels due to increasing road (rail) (air) traffic may continue to be of concern, occasionally interfering with some activities of the dwelling occupants."

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8.2 When noise control measures have been instituted on the site, and the resultant noise levels still exceed the Municipality's and the Ministry of the Environment's noise criteria by 5 dBA or less, the following wording is to be used:

"Purchasers are advised that despite the inclusion of noise control features in this development area and within the building units, noise levels from increasing road (rail) (air) traffic may continue to be of concern, occasionally interfering with some activities of the dwelling occupants as the noise level exceeds the Municipality's and the Ministry of the Environment's noise criteria."

8.3 If the Municipality accepts a noise control solution which noise level exceeds the Municipality's and the Ministry of the Environment's criteria by more than 5 dBA, the warning clause in paragraphs 8.1 and 8.2 must be reworded by replacing the word "may" with "will" or as directed by the area municipality.

8.4 When forced air heating with provision for central air conditioning is to be installed the following additional sentence is to be added to the warning clause: "This dwelling unit was fitted with a forced air heating system and the ducting, etc. sized to accommodate central air conditioning unit. (Note: locate air cooled condenser unit in a noise insensitive area.)"

9. SUMMARY SHEET

9.1 A summary sheet of the noise control measures and conclusions should be provided in the report, in order that the requirements can be easily inserted in the Subdivision or Site Plan Development Agreement. (See Table 2 of Appendix I).

10. GENERAL

10.1 Five copies of the acoustical report are required to be forwarded to the Area Municipality by the Acoustical Consultant. An additional 2 copies of the report are also required to be forwarded to the Region of Peel Planning Department if noise levels from Regional or Provincial roads are discussed. The Area Municipality shall only circulate the noise report to Ministry of the Environment when it is satisfactory to the Area Municpality and the Region.

10.2 Prior to final approval of the plan of subdivision, the Acoustical Consultant shall update the recommendations of the Acoustical Report, if required by the Area Municipality, to coincide with the proposed final M-Plan as revised for registration.

10.3 A clause shall be included in a Schedule of the Subdivision Agreement to the effect that prior to the issuance of building permits for all lots, the Acoustical Consultant shall certify that the builders plans, noise attenuation features and proposed final grading plan are in accordance with the updated detailed Acoustical Report approved by the Area Municipality, the Region and the Ministry of the Environment. The Consulting Engineer or an Ontario Land Surveyor shall certify that the grades as constructed, are in accordance with the proposed final grading plans, attached to the noise report.

Prior to the final inspection of the buildings on all lots and blocks the Acoustical Consultant shall provide certification that the constructed attenuating measures such as doors, windows, duct sizes etc. are in compliance with the acoustical report.

10.4 In preparing the Acoustical Report, regard shall be given to the relevant Official Plan policies and to the following Provincial and Federal Documents as applicable:

1. "Guidelines for Road Traffic Noise Assessment" (July, 1986). Ministry of the Environment
2. "Guidelines on Noise and New Residential Development Adjacent to Freeways". (April 1979). Ministry of Housing (now The Ministry of Municipal Affairs).
3. "Land-Use Policy Near Airports Based on the N.E.F. System". (April 1980). Ministry of Housing (now the Ministry of Municipal Affairs).
4. "Acoustic Technology in Land-Use Planning - Volume I" (November 1978) Ministry of the Environment.
5. "Road and Rail Noise - Effects on Housing". C.M.H.C. (NHA 5156 -81/10)
6. "New Housing and Airport Noise". C.M.H.C. (NHA 5185 81/5).

N.B. The above references may be revised from time to time to reflect the latest changes in the field of acoustical technology. Please ensure that you have used the lastest edition.

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APPENDIX I

NOISE IMPACT REPORT

FOR DRAFT PLAN OF SUBDIVISION 21T-

(or a site plan approval if applicable)

PREPARED FOR:

PREPARED BY:

DATE:

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

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1. INTRODUCTION

- SITE DESCRIPTION AND LOCATION
- TYPE OF DEVELOPMENT
- AREA CONTEXT
- DESCRIPTION OF NOISE IMPACT SOURCES

This section should provide a concise summary of relevant background information and an outline of the study approach and procedures.

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2. ANALYSIS PROCEDURES

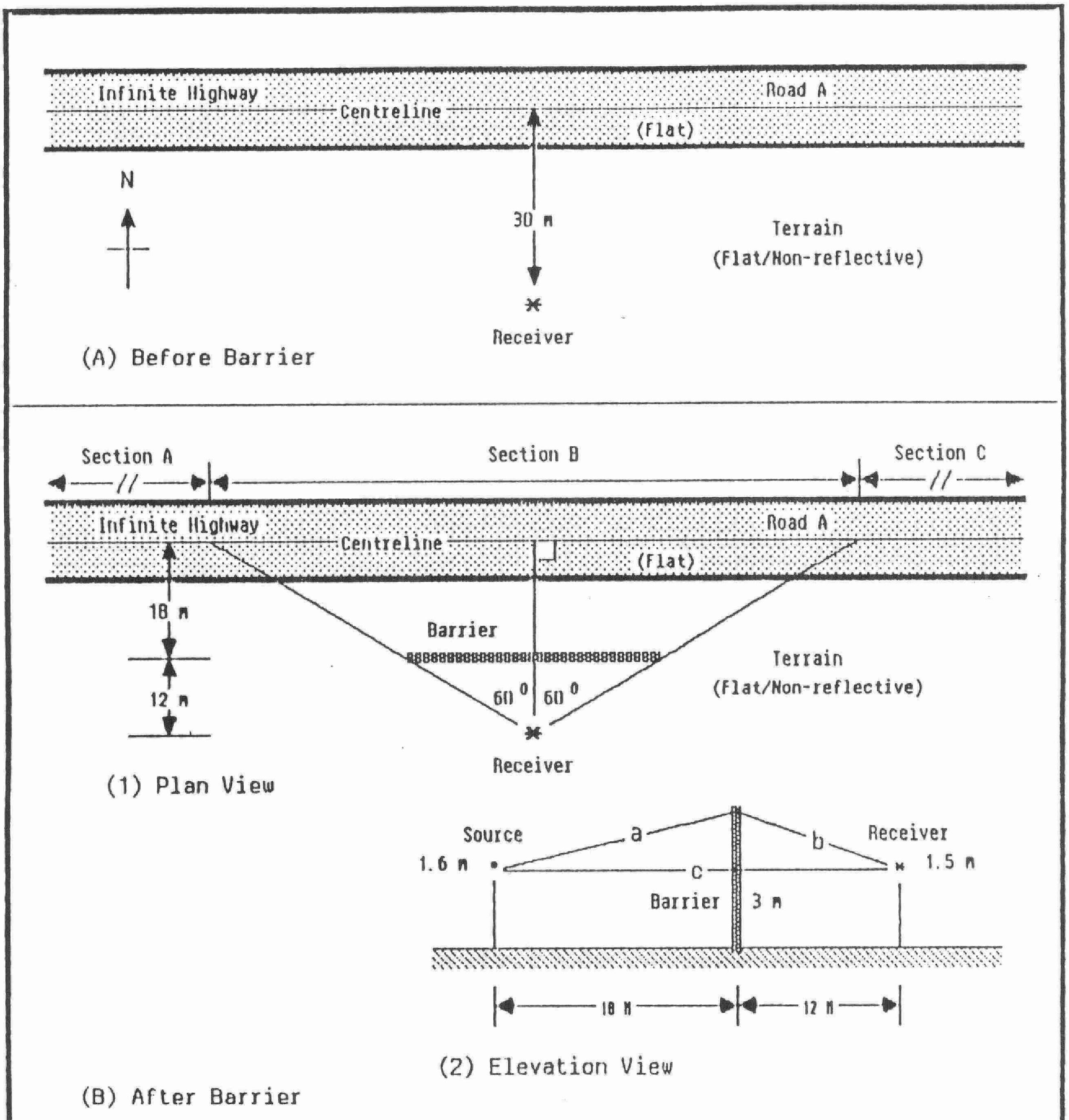
ROAD NOISE

- Identification of road Sections (elements)
- Traffic volumes (data source to be identified)
- Truck volumes (data source to be identified)
- Distances, adjustments, etc.
  (A sketch of conditions - as per Figure 1 of the MOE Guidelines should be attached).
- Traffic Noise Prediction Work Sheet
  (See Figure 2 attached) if manual calculations are used
- Computer Printouts
  if computer program is used

All data used, corrections and adjustments should be explained in the text.

FIGURE 1

Conditions On Site



(A) Before Barrier

(1) Plan View

(2) Elevation View

(B) After Barrier

Vehicles Per Hour			Posted Speed (km/h)
Passenger Cars	Medium Trucks	Heavy Trucks	
910	20	70	80

(C) Traffic Data

FIGURE 2 Sample Calculation - Before Barrier

Name J. Smith Date May 5, 1986 File LU - 5001 Project Description Road A - Before Barrier

			Road A											
1	Lanes/Road Section (Element)		EB and WB											
2	Volume -Automobiles (vph)	S 2.2(a)	910											
3	Medium Trucks (vph)		20											
4	Heavy Trucks (vph)		70											
5	Total Volume (vph)		1000											
6	Posted Speed (km/h)		80											
7	Heavy Trucks (%)		7											
	Adjusted Heavy Trucks	S 2.2(b)												
8	Road Gradient (%)		0											
9	Adjustment Factor	Table 1												
10	Adjusted Volume (vph)													
11	Medium & Heavy Trucks (%)	S 2.2(c)	9											
12	Medium Trucks (%)	S 2.2(d)	22											
13	Reference Sound Level (dBA)	Tables 3-6		59										
	Effective Heights													
14	Source (s) (m)	Table 8	1.6											
15	Receiver (r) (m)		1.5											
16	Shielding (t+p) (m)	Table 7												
17	Total Effective Height (m)	Table 7	3.1											
	Adjustments													
18	Volume (dBA)	Table 2		14										
19	Distance (m)		30											
20	Reflective (dBA)	Table 7												
21	Non-reflective (dBA)	Table 7		-5										
22	Element, θ_1 (degrees)		-90											
23	θ_2 (degrees)		90											
24	Reflective (dBA)	Table 9												
25	Non-reflective (dBA)	Table 11		-1										
26	Pavement Surface (dBA)	Table 12		0										
27	Woods (dBA)	Table 13												
28	Rows Of Houses (dBA)	Table 13												
	Barrier Shielding													
29	θ_1 (degrees)													
30	θ_2 (degrees)													
31	Finite Barrier Index	Table B1												
32	Path Length Difference (m)	Table B2												
33	Barrier Attenuation (dBA)	Table B2												
34	Section Leq(h) (dBA)			67										
35	Road Leq(h) (dBA)	Table 14		67										

"DRAFT"

AIRPORT NOISE

- N.E.F. Contour Map
- Predicted sound levels

All conversions to Leq (dBA) calculations and assumptions should be explained in the text, and illustrated on attached diagrams.

RAILROAD NOISE

- Background Data
  Type and frequency of trains, locomotives
- Calculations
- Predicted Sound Levels

All data used, adjustments and procedures should be explained in the text and illustrated on attached diagrams.

OTHER NOISE SOURCES

- Background data
- Calculations
- Predicted Sound Levels

All data used, calculations, assumptions and procedures should be explained in the text and illustrated on attached diagrams.

N.B.

Letters verifying data used should be included in an appendix.

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FOR DISCUSSION PURPOSES
ONLY

3. RECOMMENDED ABATEMENT MEASURES

ACOUSTICAL BARRIERS (See Section 5 of Guidelines)

- Calculations of PLD
  All data used and calculations should be explained in the text. A sketch of conditions and the Traffic Noise Prediction Work Sheet (Fig. 3) must be attached.

- Cross Sections (See Diagram A) as per the Guideline requirements.

- Grading Plans
  All drawings and diagrams as per Regional Guidelines must be included

- Table of Barrier Attenuation Alternatives
  The range of attenuation alternatives should be outlined as in Table 1 attached.

SITE PLAN SOLUTIONS (if applicable)
See also Section 6 of Guidelines

- Location of units

- Building design

  The report should describe all considerations and include all illustrations.

BUILDING COMPONENT SPECIFICATIONS
See Section 7 of the Guidelines

- Required AIF Ratings for Different Room activity areas

- Wall, Window, Door, Ceiling, Roof Specifications (if applicable).
  All procedures and calculations should be outlined in the report.

FIGURE 3 Sample Calculation - After Barrier

Name J. Smith Date May 5, 1986 File LU - 5001 Project Description Road A - After Barrier

			Section A				Section B				Section C			
1	Lanes/Road Section (Element)		EB and WB				EB and WB				EB and WB			
2	Volume -Automobiles (vph)	S 2.2(a)	910				910				910			
3	Medium Trucks (vph)		20				20				20			
4	Heavy Trucks (vph)		70				70				70			
5	Total Volume (vph)		1000				1000				1000			
6	Posted Speed (km/h)		80				80				80			
7	Heavy Trucks (%)		7				7				7			
	Adjusted Heavy Trucks	S 2.2(b)												
8	Road Gradient (%)		0				0				0			
9	Adjustment Factor	Table 1												
10	Adjusted Volume (vph)													
11	Medium & Heavy Trucks (%)	S 2.2(c)	9				9				9			
12	Medium Trucks (%)	S 2.2(d)	22				22				22			
13	Reference Sound Level (dBA)	Tables 3-6		59				59				59		
	Effective Heights													
14	Source (s) (m)	Table 8	1.6				1.6				1.6			
15	Receiver (r) (m)		1.5				1.5				1.5			
16	Shielding (t+p) (m)	Table 7					6							
17	Total Effective Height (m)	Table 7	3.1				9.1				3.1			
	Adjustments													
18	Volume (dBA)	Table 2		14				14				14		
19	Distance (m)		30				30				30			
20	Reflective (dBA)	Table 7												
21	Non-reflective (dBA)	Table 7		-5				-3				-5		
22	Element, θ_1 (degrees)		-90				-60				60			
23	θ_2 (degrees)		-60				60				90			
24	Reflective (dBA)	Table 9						-2						
25	Non-reflective (dBA)	Table 11		-11								-11		
26	Pavement Surface (dBA)	Table 12		0				0				0		
27	Woods (dBA)	Table 13												
28	Rows Of Houses (dBA)	Table 13												
	Barrier Shielding													
29	θ_1 (degrees)						-60							
30	θ_2 (degrees)						60							
31	Finite Barrier Index	Table B1					20							
32	Path Length Difference (m)	Table B2					.148							
33	Barrier Attenuation (dBA)	Table B2						-9						
34	Section Leq(h) (dBA)			57				59				57		
35	Road Leq(h) (dBA)	Table 14		62.5										

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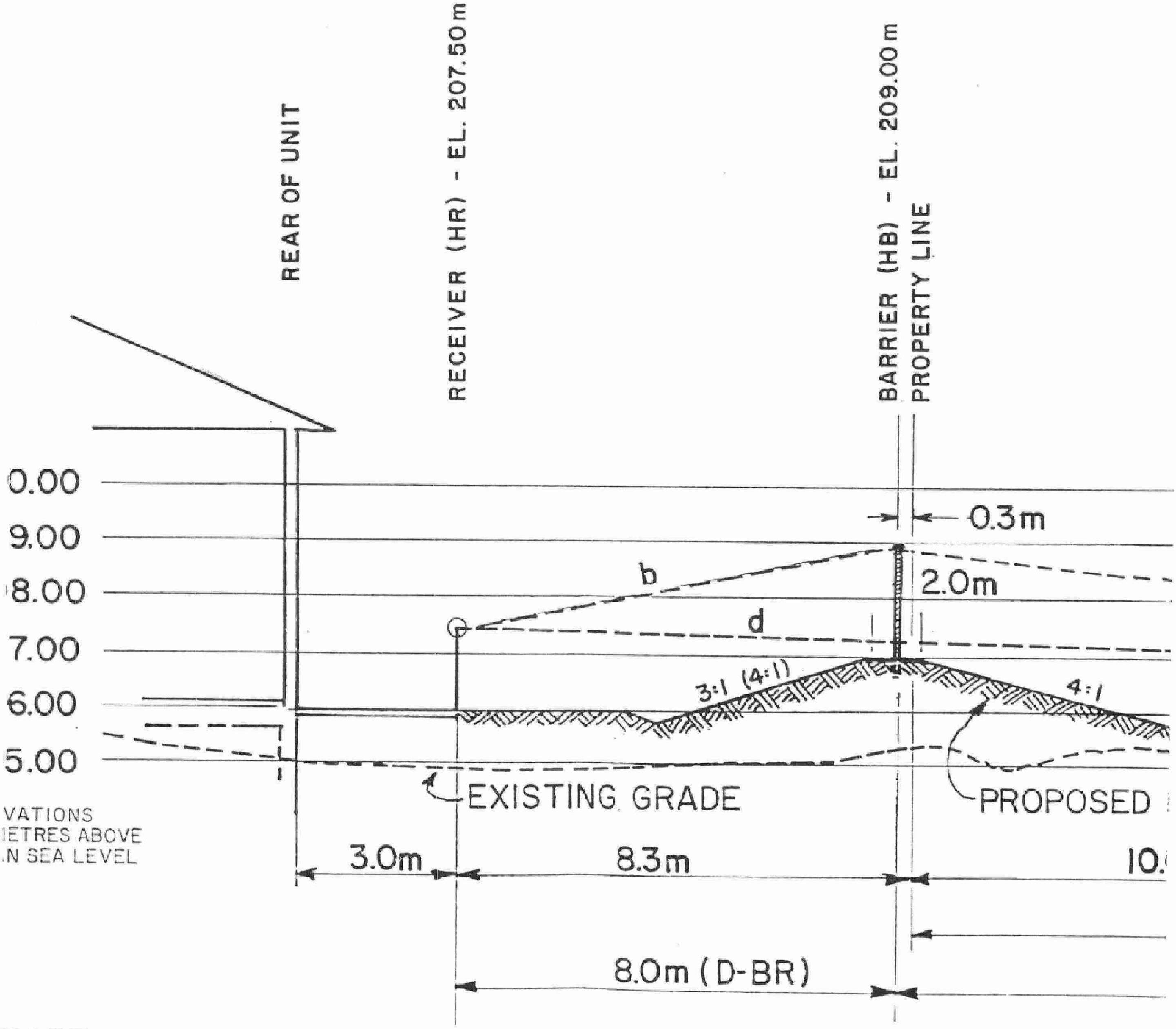

PORTANT NOTE:

'QUIRED DRAWINGS MUST BE
) 1:50 or 1:100 SCALE ONLY.

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TYPICAL CROSS SECTION

SCALE= 1:100

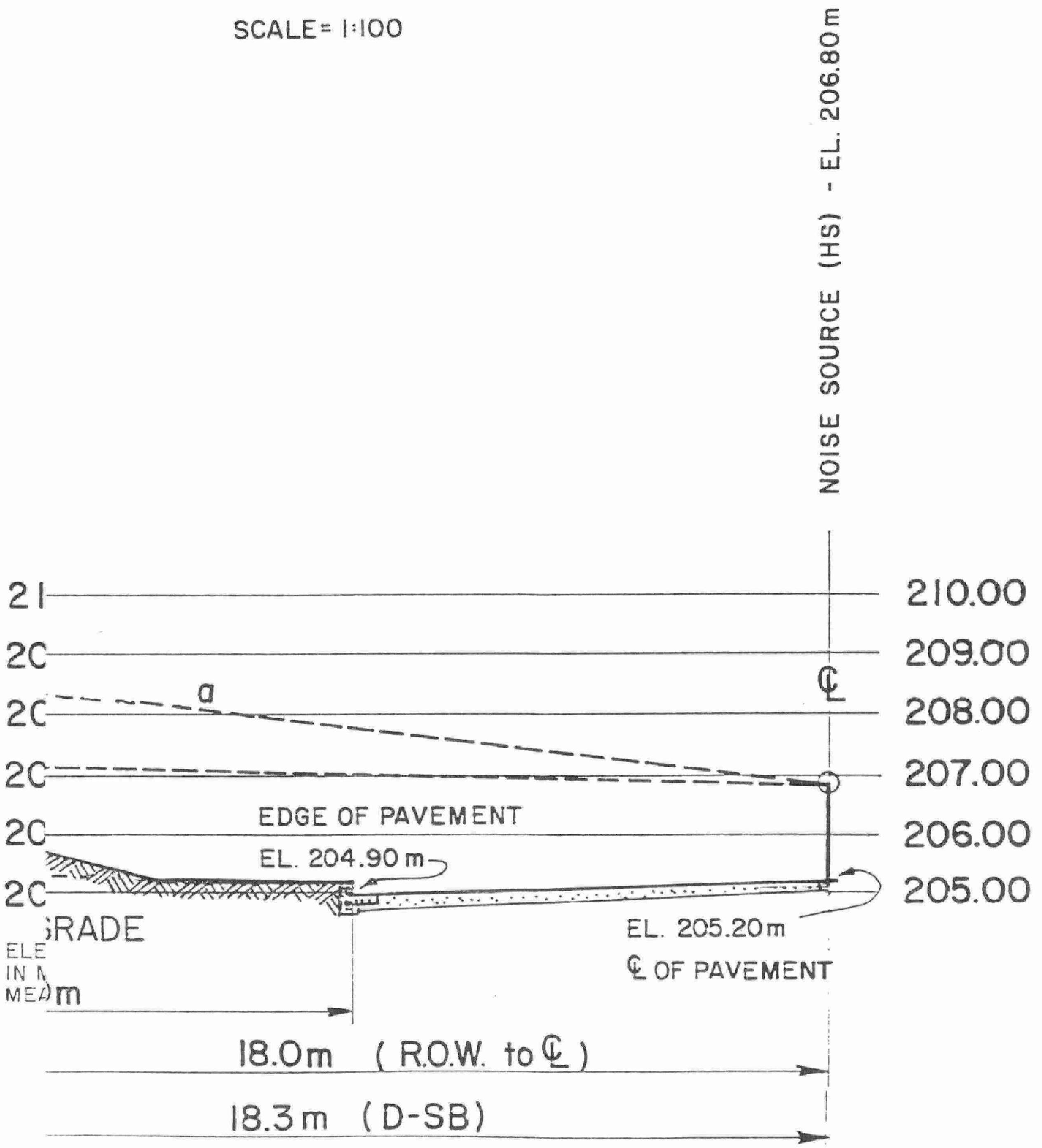

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DIAGRAM 'A'

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REGION OF PEEL PLANNING DEPT. 861214 IAP/MDC/MJB

TABLE 1

ACOUSTICAL BARRIER ATTENUATION ALTERNATIVES*

Proposed Grade Difference to base of barrier (above edge of pavement)	Wall Height	HB (Effective Height)	HS (above edge of pavement)	HR (above edge of pavement) 1.52m above ground	DSB	DBR	a (Distance from source to top of HB)	b (Distance from top of HB to receiver)	d (source to receiver path)	PLD ((a + b - d) path length difference)	N (Fresnel Number)	Attenuation	Leq (Calculated outside level)	Leq (Resultant outside level)
1.6	2.0	3.6	3.0	2.7	10.0	8.3	10.0179	8.3486	18.3024	0.064	0.185	8 dBA	62 dBA	55 dBA
2.2	1.4	3.6	3.0	2.7	10.0	8.3	10.0179	8.3486	18.3024	0.064	0.185	8 dBA	62 dBA	55 dBA
2.2	2.0	4.2	3.0	2.7	10.0	8.3	10.0717	8.4344	18.3024	0.203	0.588	9 dBA	62 dBA	53 dBA

* All units of measurement in metric

HB - height of barrier
HS - height of noise source
HR - height of noise receiver
DSB - distance from noise source to barrier
DBR - distance from barrier to receiver

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4. SUMMARY OF NOISE ATTENUATION MEASURES

All recommendations should be summarized for inclusion in the development agreement and listed in a table. (See Table 2 attached). Relevant warning clauses should also be quoted.

TABLE 2

SUMMARY OF MINIMUM NOISE ATTENUATING MEASURES*

Lot Number	Central Air Conditioning	Exterior Walls	Windows		Amenity Areas	Warning Clauses
		Type	Space**	AIF		
1-11 See Text	Yes	EW1	Bedroom -	32	At rear of houses Lot 1: see text 1.8 m sound barrier	Yes
			Living Room -	27		
			Kitchen -	22		
12-16	Yes	EW4 or EW5 or EW1R	Bedroom -	34	At rear of house Lot 16: see text 1.8 m sound barrier	Yes
			Living Room -	29		
			Kitchen -	24		
17-31	Yes	EW5 or EW1R	Bedroom -	38	At rear of house: see text Lot 17 garage at south side. Lot 31 garage at north side.	Yes
			Living Room -	33		
			Kitchen -	28		

---

* For detailed description of noise attenuating measures, see the report

** Data applies to room envelopes with 2, 3, or 4 components

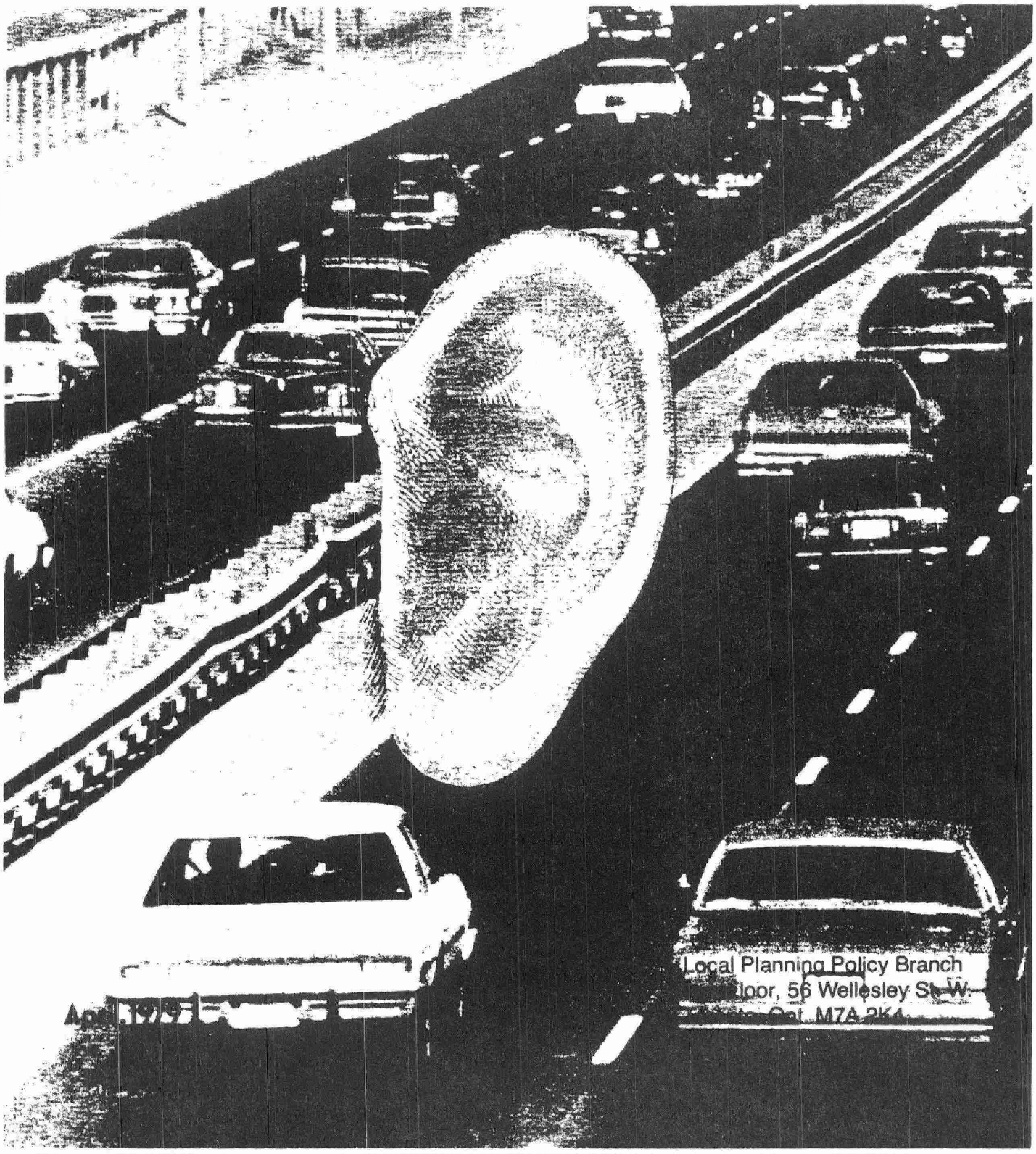
APPENDIX H

GUIDELINES ON NOISE AND NEW RESIDENTIAL DEVELOPMENT ADJACENT TO FREEWAYS

Ontario

Ministry of
Housing

Guidelines on noise and new residential development adjacent to freeways



April 1979

Local Planning Policy Branch
[illegible] Floor, 56 Wellesley St. W.
Toronto, Ont. M7A 2K4

Minister's statement on noise and new residential development adjacent to freeways

Mr. Speaker:

In February of 1977, the Ministers of Transportation and Communications and Housing announced that, "where feasible," noise barriers would be provided by the Ministry of Transportation and Communications for new construction work on major freeways through existing residential areas. It was also stated that developers of new residential units near freeways would have to include similar measures to reduce noise impact.

We are now able to introduce guidelines to control the noise in outdoor areas of new residential developments near freeways. I am pleased to announce a new policy which has been formulated in consultation with the Ministries of the Environment, and of Transportation and Communications.

Briefly, Mr. Speaker, this new policy sets an objective of 55 decibels as an outdoor noise level in residential developments adjacent to freeways. Where the outdoor noise level is likely to be excessive, the developer must demonstrate that measures will be taken to get as close as possible to this objective level of 55 decibels.

In those cases where the attenuated outdoor noise level exceeds 70 decibels, residential development will be prohibited, because this is the level where extensive community dissatisfaction occurs.

My ministry, in co-operation with the Ministries of the Environment and of Transportation and Communications, will be forwarding guidelines on outdoor noise levels for new residential development to all municipalities. This material also indicates some techniques which could be used to reduce the noise impact. Copies of these guidelines will also be provided to all members.

Noise control guidelines are also being prepared relative to the *indoor* sound environment, and these should be ready in the near future.

Guidelines on noise and new residential development adjacent to freeways

Introduction

A policy dealing with current problems of freeway noise in *existing residential areas* and with noise problems associated with freeway construction or reconstruction through *existing residential areas* was jointly announced by the ministers of Transportation and Communications, and of Housing in February 1977. It stated that, *"where feasible"*, noise barriers would be provided and that a developer, proposing to build residential units adjacent to a freeway, would be required to take appropriate measures to reduce noise impact.

It is unrealistic to suggest prohibiting all new residential development close to freeways since it is often technically, administratively and economically practicable to design new developments and/or incorporate measures in such a manner that noise is reduced to acceptable levels. Also, it is recognized that developers have varying degrees of flexibility to attenuate sound.

Consequently, it was considered desirable to establish sound level limits for noise control in *outdoor recreational areas* for new residential development adjacent to freeways. (Appropriate noise control guidelines are being prepared by the Ministry of Housing to ensure that the *indoor sound environment* of new residential development near freeways is also protected.)

Definition of 'freeway'

For the purposes of this policy, "freeway" is defined as an existing completed, partially developed or proposed provincial or municipal divided arterial highway that is accessible only from intersecting arterial streets at grade-separated interchanges.

Definition of 'outdoor recreational area'

For the purposes of this policy, "outdoor recreational area" is defined to mean an outdoor living area immediately adjacent to the housing unit designed to accommodate a variety of individual outdoor activities.

Sound level measurement

For the purposes of this policy, the noise level is the A-weighted 24-hour equivalent (L_{eq}) sound level based on either the Average Annual Daily Traffic (AADT) data or, where available, the Summer Average Daily Traffic (SADT) data, whichever is the higher. The equivalent (L_{eq}) sound level is a good indication of how people react to freeway noise.

Generally, the public reacts to noise when sound levels in outdoor recreational areas exceed 55 decibels (dBA). Public concerns, dissatisfaction, and complaints increase rapidly from approximately this level.

Policy on noise and new residential development adjacent to freeways

- The objective for predicted sound levels in outdoor recreational areas is 55 dBA or less.
- The province will not impose additional noise attenuation on the developer where the level is at or below the objective level.
- The developer shall be required to prove to the satisfaction of the approving authority, in accordance with provincial guidelines, that the noise level in outdoor recreational areas after applying attenuation measures is the lowest level technically, administratively and economically practicable. Any consideration of relief from achieving the objective level will be based on specific site characteristics, such as topography, existing development and the available sound attenuation options. Residential development will be prohibited where the *attenuated sound level* in outdoor recreational areas will exceed 70 dBA.
- The Ministry of Transportation and Communications shall plan to achieve an *attenuated sound level* as low as technically, administratively and economically practicable below 70 dBA where a freeway is proposed to be built or expanded through a developed residential area.
- Where the noise levels are expected to exceed 55 dBA in outdoor recreational areas after the implementation of sound attenuation measures, the approving agency for any new residential development shall require as a condition of approval that the developer inform prospective purchasers of residential lots which are so affected of the noise situation by posting a sign or by other appropriate means.
- Where residential development for which noise control measures will be required precedes the construction of a designated freeway, the approving agency *may require* as a condition of approval that:
  - (a) sufficient lands be conveyed at no cost for erection of a noise barrier; and/or,
  - (b) a pro-rated cost contribution be made prior to final approval for barrier construction, if barriers are considered necessary at the time of final approval.

Purpose of guidelines

The purpose of these guidelines is to ensure that sufficient data is made available by a developer to the approving authority demonstrating the achievement of the lowest technically, administratively and economically practicable noise levels for new residential development, in accordance with the provincial policy on Noise and New Residential Development Adjacent to Freeways. The analysis and evaluation by the approving authority will consist of checking the validity of the submission based on the best available acoustical information.

Noise control measures

In order to obtain relevant information for noise attenuation, a developer should make early contact with the Ministry of the Environment when the development is within one kilometre of the edge of a freeway right-of-way. The distance may vary with different conditions of traffic, topography and existing development.

Any consideration of relief from achieving the objective level of 55 dBA will be based on specific site characteristics, such as topography, existing development and the available noise control options. Control measures may include, but are not limited to, the following:

i) **Site Planning**—orientation of buildings and outdoor recreational areas with respect to noise sources, spatial separation such as insertion of sound-insensitive land uses between source and receiver and appropriate setbacks; and

ii) **Acoustical Barriers**—berms, walls, favourable topographical features, other intervening structures.

Guidelines

Land use planning principles

Planning principles should be adopted that minimize the chances of creating noise problem areas. Put simply, it means a proper place for every land use so that each use is compatible with the surroundings.

The overall goal should be to reduce the amount of residential land adversely affected by freeway noise. Residential areas should normally be located away from freeways. Wherever possible, commercial, light industrial, recreational and agricultural uses should buffer residential areas from noisy freeway traffic. If a residential area must be located near a freeway, suitably-designed medium and high density residential buildings are more adaptable to the noise environment than low density single-family units. Also, they perform the function of the noise barrier (barrier block) for the rest of a residential site.

Official plans and amendments

(a) If an official plan, relevant amendment, or secondary plan is under preparation, a municipality should consult with the Ministry of the Environment regarding appropriate noise control statements to be included in the plan.

(b) When an official plan or relevant amendment is submitted to the Region or the Ministry of Housing for approval, the provincial policy on Noise and New Residential Development Adjacent to Freeways will be included in the plan or amend-

ment by modification if the municipality has not already done so.

Plans of subdivision

(a) Prior to making a subdivision application, a developer should obtain information on the necessary actions to be taken from the Region or the Ministry of Housing. At this stage, a developer may be instructed to consult the Ministry of the Environment and the Ministry of Transportation and Communications.

(b) When the plan of subdivision is submitted to the Region or the Ministry of Housing for approval, the Region or the Ministry of Housing will ensure that the subdivision conforms to the provincial policy by circulating the plan of subdivision to the Ministry of the Environment and the Ministry of Transportation and Communications for comments and technical advice on noise control measures.

(c) The Region or the Ministry of Housing, upon weighing this advice against other technical, administrative and economic considerations, may then give draft approval with appropriate conditions.

The implementation of the conditions will be achieved through a subdivision or development agreement.

Zoning bylaw amendments

(a) Since site planning is a major noise control measure, municipalities should use Section 35a of *the Planning Act* to implement appropriate conditions*. Publications on noise control measures are available from the Ministry of the Environment.

(b) Before passing a zoning bylaw amendment for a development affected by freeway noise, a municipality should refer the amendment to the Ministry of the Environment for comments.

(c) If the municipality passes such a bylaw without having regard to the provincial policy, the Region, the ministries of Housing, the Environment and, if a provincial freeway is involved, the Ministry of Transportation and Communications, will have to determine whether or not a potential noise problem exists and, if necessary, may object to the Ontario Municipal Board.

Special information required

The information required for review and evaluation of proposals for new residential development should include the following:

(a) **Location of freeways-**The plans should indicate the existing or planned future location of freeways within one kilometre.

(b) **Site plan-**The site plan should show the topography of the site, elevation and layout of the various existing buildings or proposed structures.

(c) **Establishing the noise levels on site-**The noise levels anticipated on the site should be established by the use of prediction techniques acceptable to the region and the Ministry of the Environment based, when necessary, on actual measurements. In all cases, consideration should be given to anticipated future increases in noise levels for at least ten years.

Current traffic information and traffic predictions for any particular provincial freeway may be obtained from the Ministry of Transportation and Communications. Developers may obtain further information on traffic noise prediction techniques from the most up-to-date government publications, from acoustical literature, and from the Noise Pollution Control Section of the Ministry of the Environment, Toronto.

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*Ministry of Housing. *Guidelines for Development Control (Site Plan Control) — The Planning Act: Section 35a*. February 1975.

2.5M/4-79/PW-88

APPENDIX I

INITIAL COMMENTS PROCEDURE FOR NOISE IMPACT ON PROPOSED RESIDENTIAL SUBDIVISIONS

ENVIRONMENTAL APPROVALS AND
LAND USE PLANNING BRANCH

NOISE ASSESSMENT UNIT

INITIAL COMMENTS PROCEDURE FOR NOISE IMPACT ON PROPOSED RESIDENTIAL SUBDIVISIONS

JUNE 1986

Ministry of the Environment
Ministère de l'Environnement
Ontario

Environmental Approvals and
Land Use Planning Branch

135 St. Clair Avenue West
Suite 100
Toronto, Ontario
M4V 1P5

135 ouest, avenue St. Clair
Bureau 100
Toronto (Ontario)
M4V 1P5

June 17, 1986

NOISE COMPATIBILITY REVIEW OF NEW RESIDENTIAL LAND USES

The Regional and District offices have the lead function in providing co-ordinated comments on noise to the appropriate approving authorities, such as the Ministry of Municipal Affairs or the local municipality. The Noise Assessment Unit in my Branch provides assistance to the regional offices in technically complex situations.

The noise review is generally divided into two (2) stages: review and comments prior to Draft Approval, referred to as Initial Comments, and review and comments prior to Final Approval. The Noise Assessment Unit's function normally translates to providing assistance in the Final Plan Approval stage; Initial Comments are generally straightforward and, therefore, the responsibility of the region.

In order to clarify the Initial Comments Procedure for Noise Impact on Proposed Residential Subdivisions, staff of the Noise Assessment Unit have prepared the attached procedural flowchart. This chart describes the possible noise impact scenarios, presents the applicable noise guidelines and recommends conditions to be used for the Draft Plan approval.

T. D. Armstrong, P. Eng.
Acting Director

INITIAL COMMENTS' PROCEDURE

FOR NOISE IMPACT ON PROPOSED RESIDENTIAL SUBDIVISIONS

OVERVIEW

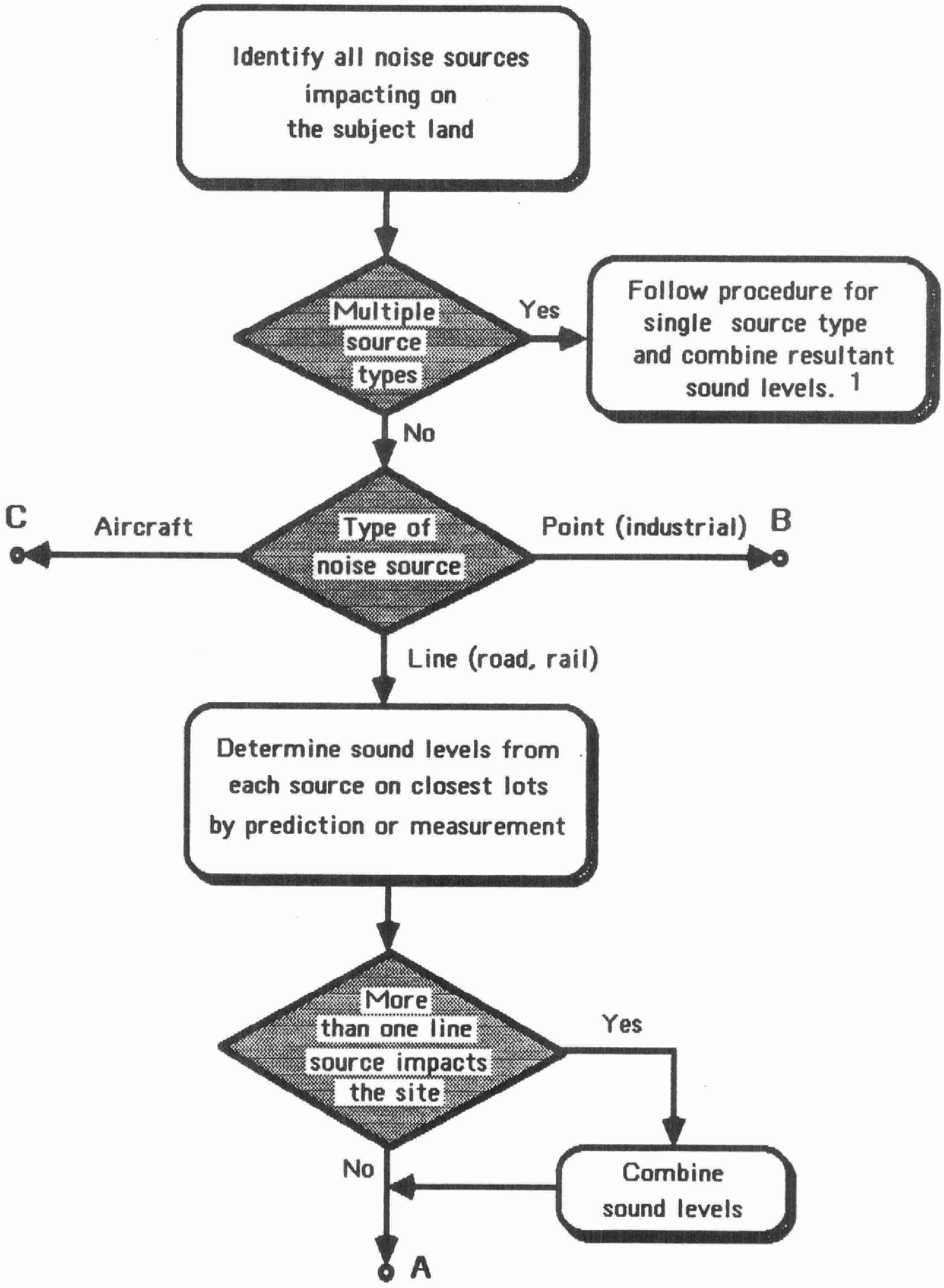
The objective of the enclosed flowchart is to provide a clear and simple procedure for the assessment of noise impact. Road, rail, aircraft and industrial sources of noise are addressed.

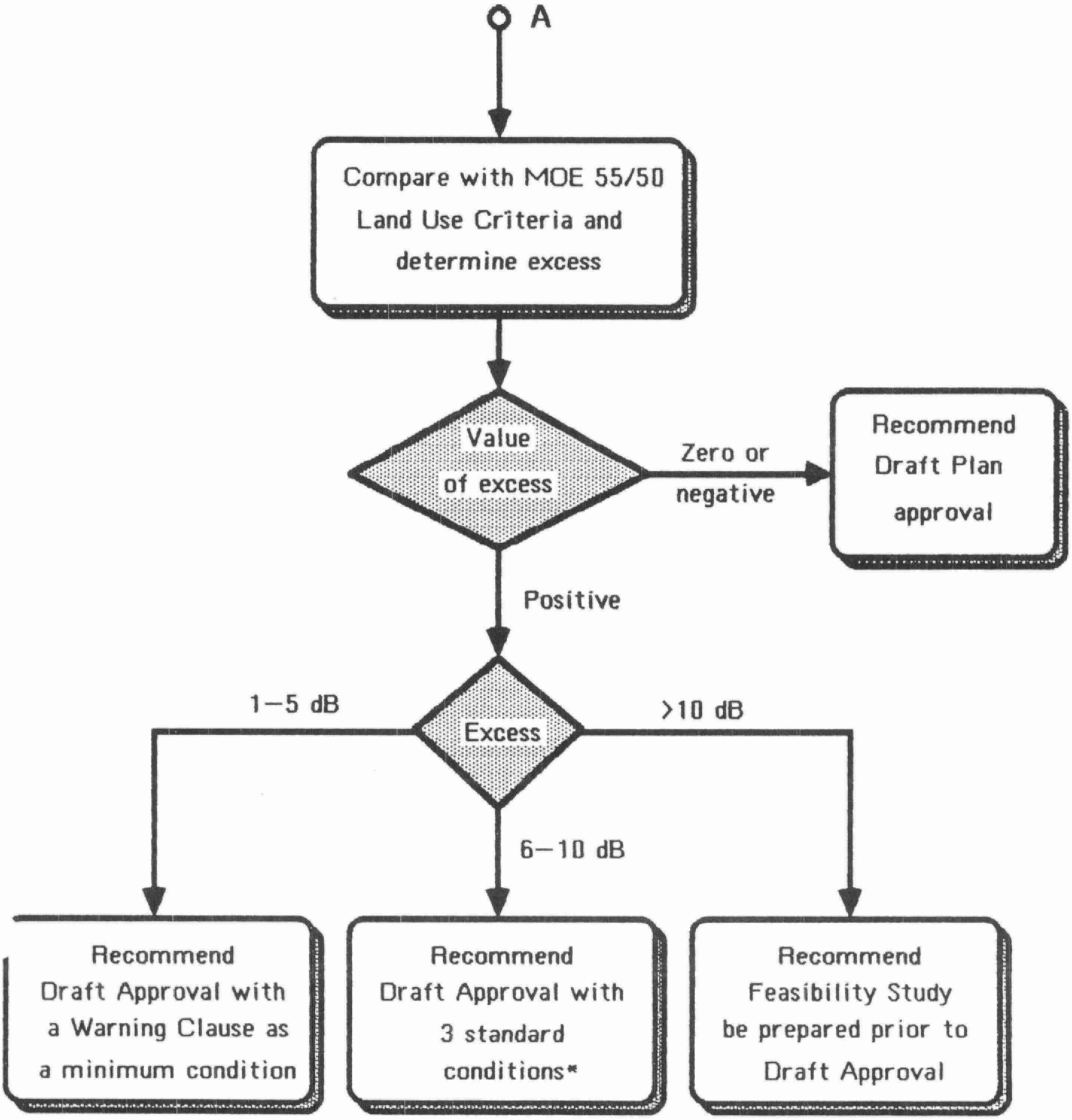
The assessment is intended to be conservative: if any uncertainty exists regarding the level of impact, the larger value should be used for comparison with the guidelines.

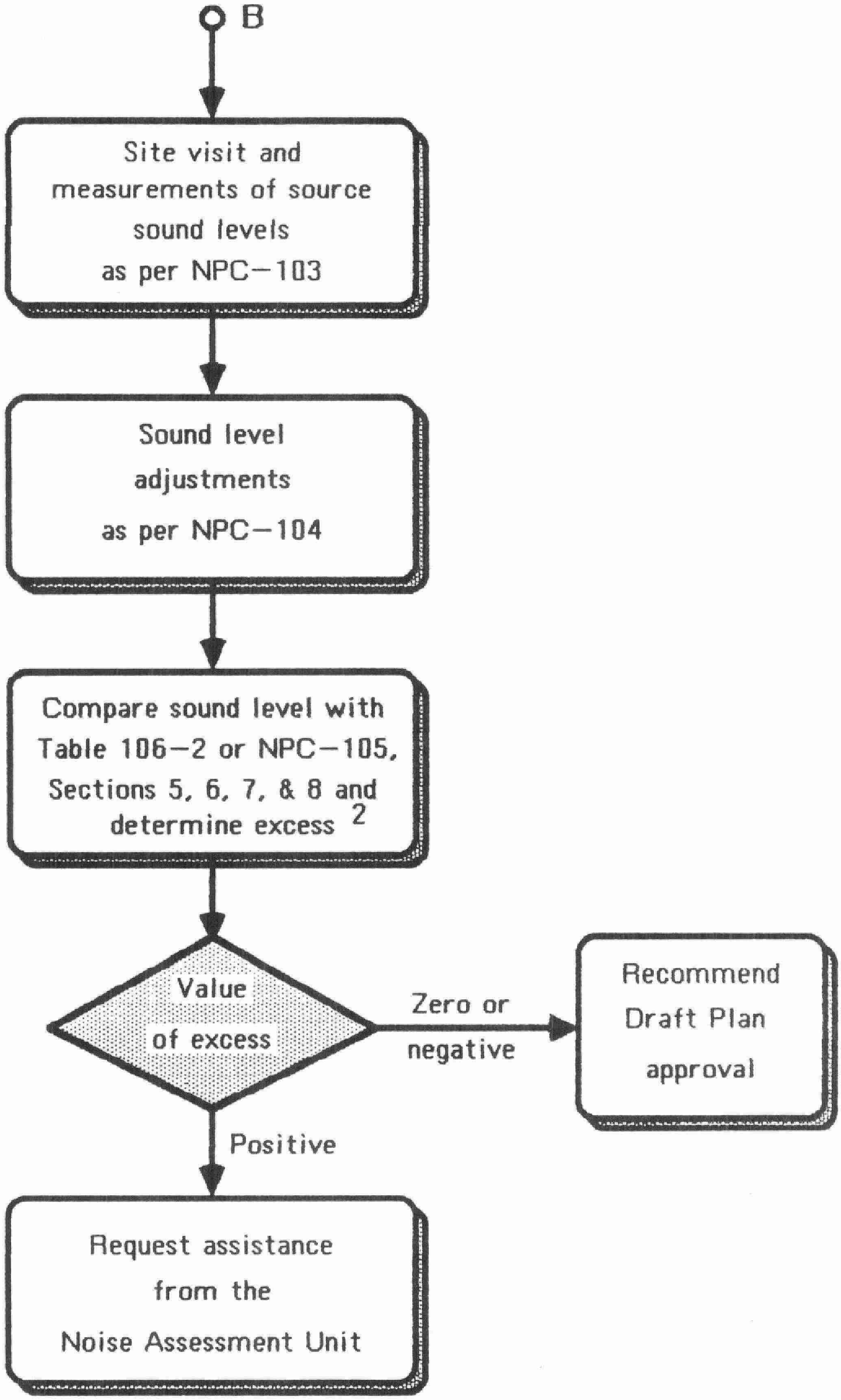
Whenever possible, the submissions are to comply with the identified MOE guidelines of 55/50 dBA, NEF 25, etc. In particular, the "warning clause" recommendation is discretionary and should be given only when the excess is clearly within 5 decibels; else, recommendation for "three standard conditions" should be given.

June 1986

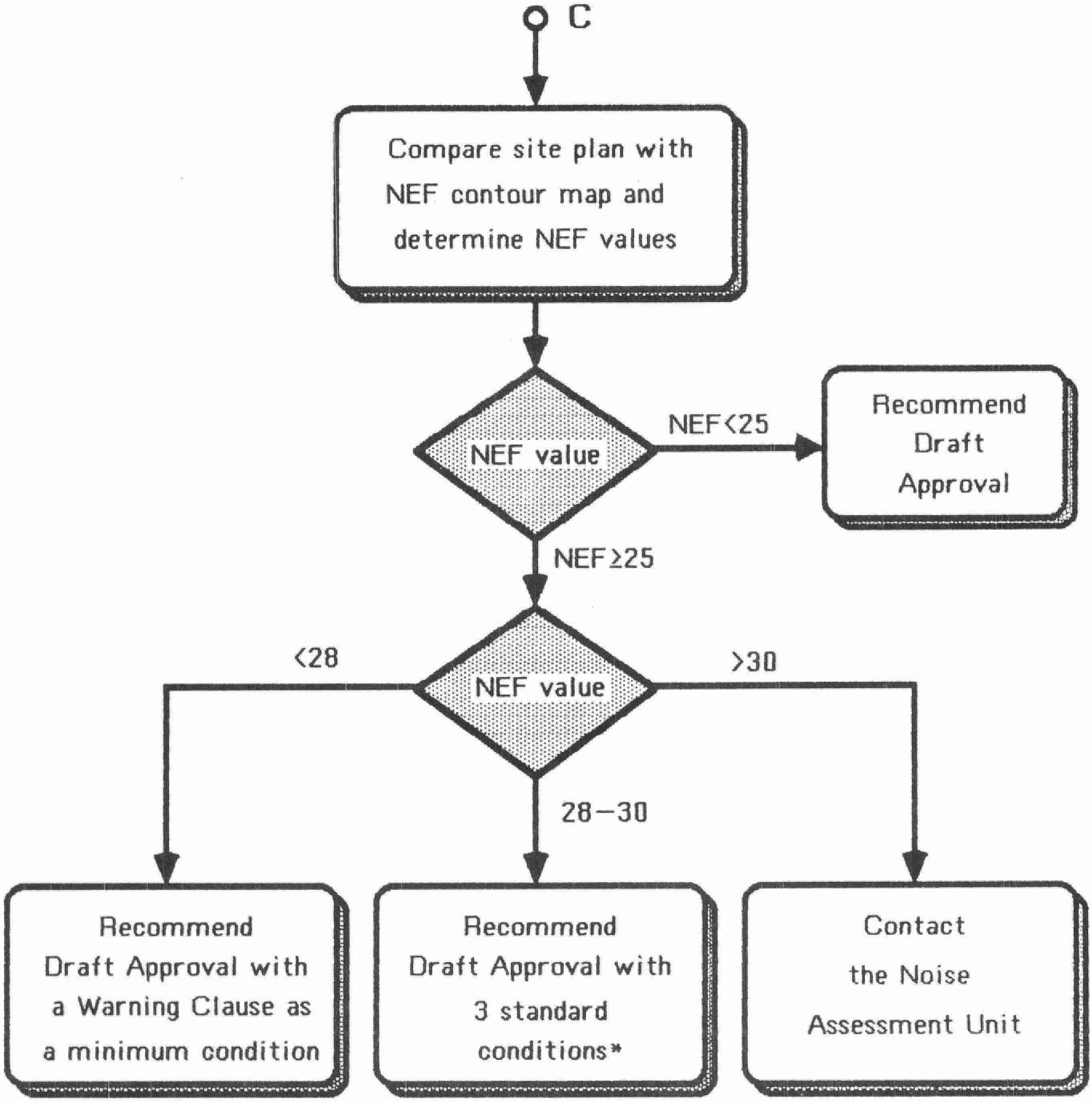
INITIAL COMMENTS' PROCEDURE
FOR
NOISE IMPACT ON PROPOSED RESIDENTIAL SUBDIVISIONS




A
Compare with MOE 55/50 Land Use Criteria and determine excess
Value of excess
Zero or negative
Recommend Draft Plan approval
Positive
Excess
1–5 dB
>10 dB
6–10 dB
Recommend Draft Approval with a Warning Clause as a minimum condition
Recommend Draft Approval with 3 standard conditions*
Recommend Feasibility Study be prepared prior to Draft Approval



[2] NOTE: Comparison is to be made with sound level limits in NPC–105 with the exception that limits for sounds specified in Section 4, Sound Level Limits – General, be replaced by Table 106–2.



[1] NOTE: To arrive at a resultant sound level produced by aircraft and road/rail traffic, use the following procedure :

- Sound Level from NEF value: $L_{eq} = NEF + 31$ dBA
- Combine L_{eq} values produced by aircraft and road/rail using logarithmic addition of sound levels.
- Compare the resultant sound level with MOE 55/50 Land Use Criteria.
- Contact the Noise Assessment Unit if necessary.

* DRAFT PLAN APPROVAL

THREE STANDARD CONDITIONS

It is recommended that the following three (3) conditions be included in the draft approval of the plan:

1. Prior to final approval of the plan, the owner/developer shall investigate the noise levels on the site and determine the noise control measures which are satisfactory to the Ministry of the Environment and the municipality in meeting the Ministry's recommended sound level limits for proposed residential land uses. An acoustical report prepared by a qualified Professional Engineer containing the recommended control measures shall be submitted to the municipality/approving authority in duplicate.

2. Prior to final approval of the plan, the Ministry of the Environment shall be in receipt of a copy of the fully executed subdivision agreement between the owner and the municipality stating that the specific noise control measures, recommended in the acoustical report in accordance with condition 1., and any other additional measures, recommended by this Ministry, shall be completed by requirement of the subdivision agreement.

3. In the event that, after the approved noise control measures are installed, the Ministry's recommended sound level limits for proposed residential land uses are not fully achieved resulting in a marginal excess, the subdivision plan shall make provision for the inclusion of a warning clause for specified lots in the proposed development and this warning clause shall be registered against the lands to which it applies and included in every offer to sell an affected lot. The minimum requirement for a warning clause is as follows:

   "Purchasers are advised that despite the inclusion of noise control measures within the development area and within the individual building units, noise levels may become of concern, occasionally interfering with some activities of the occupant."